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PHYSICAL AND MECHANICAL PROPERTIES OF PRESSURE VESSEL MATERIAL FOR APPLICATION IN A CRYOGENIC ENVIRONMENT

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Yearly Summary Report

15 May 1963 ~~to~~ 15 May 1964

Contract AF33(657)-11289, ~~Phase II~~

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ABSTRACT

The Yearly Summary Report on the work performed under Contract AF33(657)-11289, Phase II, briefly describes the objectives of this investigation. A discussion of the test program, selection of test materials, ~~and~~ brief description of ~~the~~ test specimens and ~~testing~~ apparatus is given. ~~The~~ test results ~~obtained to date are presented and~~ discussed. ~~The~~ test data include tensile, notched tensile, weld tensile, axial fatigue, and crack propagation properties of 7039-T6 aluminum alloy, 18% nickel maraging steel, Hastelloy B, and 718 nickel base alloy from 75° to -423°F. Plans for future work, ~~including a~~ program ~~schedule~~ are given.

1. INTRODUCTION

The progress made under Phase II of the subject contract from 15 May 1963 to 15 May 1964 is presented. This program is a continuation of Contract AF33(657)-7719; therefore the reader is referred to the final reports (References 1 and 2) on the original programs for background information.

The primary objective of the original contract was to develop simple laboratory-type tests to evaluate the toughness of several high-strength sheet alloys and the resistance of complex welded joints under repeated axial loading at cryogenic temperatures. Such tests may be used to screen candidate materials, evaluate newly developed engineering alloys, and serve as inspection and quality control tests to assure that sheet alloys having the requisite fracture resisting qualities are employed in critically stressed structures. A secondary objective of the program was to acquire useful engineering data on the mechanical properties of a number of high-strength sheet materials for advanced missile and space vehicle applications. The data obtained under the original contract have shown the value of the notched tensile test for screening candidate structural materials. Also, the engineering data have been extremely beneficial to the government and to industry as witnessed by the large amount of interest shown in the program.

The objectives of the present contract are threefold: to evaluate the toughness and fatigue resistance of complex welded joints of several high strength alloys of interest for aerospace applications; to acquire data useful to design and materials engineers on the mechanical properties of these alloys from 75° to -423°F; and to obtain quantitative fracture

toughness data, in the presence of cracks or defects, on materials which have been found by screening tests to be promising for structural applications.

More than seventeen hundred tests have been completed to date. Details of the test program, materials, specimens and apparatus are discussed in addition to a summary of the present test results.

2. TEST PROGRAM

The test program consists of two parts: mechanical property testing and fracture toughness testing.

Mechanical property testing includes the determination of the following properties for 7039 aluminum, 18% nickel steel, and Hastelloy B and Inconel 718 nickel base alloys:

Yield strength (0.2% offset) of parent material

Ultimate tensile strength of parent material

Elongation of parent material

Notched tensile strength (K_t of 6.3) of parent material

Notched tensile strength (K_t of 21) of parent material

Ultimate tensile strength and elongation of fusion welds

Tensile and shear strengths of spot welds

Axial fatigue resistance of complex welded joints
(cycled from 0 to 75, 85 and 95% of typical yield strengths in order to develop the low cycle portion of the S-N diagram)

The fatigue and static tests of complex welded joints are being performed at 75°, -320° and -423°F, whereas all other mechanical property tests are conducted at 75°, -100°, -320°, and -423°F. Also hardness and magnetic determinations, calculations of elastic moduli and proportional limits and metallographic studies are being made. The mechanical property tests were conducted in the same manner as was used for specimen testing in the original program (References 1 and 2).

Fracture toughness tests are being conducted on nine high strength engineering sheet alloys. Basic fracture toughness (K_c) and strain energy release rate (G_c) data are being developed at 75, -320, and -423°F for

both the longitudinal and transverse directions. From these data critical crack lengths are plotted as a function of stress and temperature. The rate of crack growth under static loading is determined during the above mentioned tests. The rate of crack growth under cyclic loading is being determined at 75, -320, and -423°F at three different stress levels. The stress levels are at very high proportions of the yield strength or maximum load carrying ability (60, 75 and 90%) of the specimen since it is the high stress levels which are of most interest to the design engineer of modern aircraft, missiles, and space vehicles. Incorporation of the initial crack length and crack growth rate data will give the design engineer the most quantitative laboratory test data available for selecting the optimum material for cryogenic structural applications. In addition to the above testing, an investigation is underway to study the effects of:

Specimen width

Initial crack length

Material thickness, and

Loading rate

on the fracture toughness (K_c) and strain energy release rate (G_c) properties. Fracture toughness tests are being conducted in the same manner as was used in the original program (Reference 2).

All tests are performed in replicate (minimum of five acceptable tests). The total number of tests required under the program is 3320, although a considerably larger number of tests are being conducted in order to understand and interpret the test results.

3. TEST MATERIALS

The materials selected for study include 2219 and 7039 aluminum, type 304 stainless steel and 18% nickel maraging steel (250 grade), Hastelloy B, René 41 and type 718 nickel base alloys, and Ti-5Al-2.5Sn ELI and Ti-6Al-4V ELI titanium alloys. These materials were chosen for immediate study because of many reasons: 1) They represent alloys which are currently being used in the construction of missiles and space vehicles or are presently being proposed or considered for use in missile and space craft production. 2) These alloys represent two fundamentally different methods of obtaining their high strengths. These are cold-rolling (304 S.S., Hastelloy B and Inconel 718) and heat-treatment (2219 and 7039 aluminum alloys, Rene 41, 18% nickel steel and type 718 nickel base alloy). The titanium alloys will be tested in the annealed condition. 3) These materials cover a wide range of resistance to brittle fracture, particularly at cryogenic temperatures. 4) The alloys are commercially available at a reasonable cost and may be fabricated (formed, machined, welded) for structural applications. 5) A large amount of service data are available on most of the materials. 6) Previous investigation (at GD/Astronautics as well as at several other cryogenic testing laboratories) have shown these materials to be the most promising for sub-zero temperature applications. 7) There is a large amount of metallurgical knowledge available which is beneficial in understanding and explaining the results of the test data.

All of the materials to be used in this investigation have been delivered and fabricated into test specimens. History and chemical analysis of the test materials is given in Table 1.

4. TEST SPECIMENS

The test specimens being used in this investigation for the determination of mechanical properties include the following:

Unnotched tensile (for parent metal and fusion welds)

Notched tensile (K_t of 6.3 and 19)

Spot weld tensile and shear

Complex welded joint (for static and axial fatigue tests)

These test specimens are the same as those used in the original investigation, and full details of the specimens, configurations and dimensions may be found in Reference 1.

The test specimens being used for fracture toughness testing are center notched specimens with widths of 2, 4, and 18 inches. Notch lengths vary from 0.60 to 5.50 inches. For purposes of studying the effects of material thickness, notch length and loading rate on the crack propagation of high strength sheet materials, a large number of the four inch wide specimens are being fabricated with various material thicknesses (0.015 to 0.125 inches) and notch lengths (0.25 to 1.75 inches). The specimens were designed so that slow crack growth would occur prior to onset of rapid crack propagation. Whenever possible, the suggestions of the Fracture Toughness Committee of the ASTM (Reference 3) were used as a basis for design of the crack propagation specimens. To offset the recommended width to thickness ratio the use of doublers and end fixtures were used to help prevent lateral buckling.

The procedure for specimen preparation was as follows. Specimen layout and identification was made on the sheet materials. Specimen blanks were then sheared and those specimens requiring fusion or resistance roll

seam welding were welded. The fusion-weld, spot-weld, and roll-seam-weld schedules are given in Tables 2, 3, and 4. All the welds were visually inspected and many were inspected by means of an x-ray examination. The specimen blanks were then machined and surfaces prepared for testing and then inspected. Any specimens which were not within the dimensional tolerances of the machining prints were discarded. Doublers were then spot welded on the fatigue specimens. Notched tensile specimens were measured by means of an optical comparator. Smooth tensile, fatigue, and crack propagation (for thickness) specimens were measured to 0.0001 inch by means of a micrometer.

The following progress has been made on specimen fabrication:

Type Specimen	Minimum Number to be fabricated	Number of Specimens in Fabrication	Number Completed
Tensile	160	0	220
Notched Tensile	320	0	440
Weld Tensile	160	0	350
Spot Weld Tensile	320	0	360
Spot Weld Shear	320	0	360
Axial Fatigue	240	0	280
Crack Propagation	1350	40	1440
	2870	40	3450

It is to be noted that a significantly larger number of test specimens have been or are being fabricated than required by the contract. This is due to two reasons; the fabrication of spare test specimens and the inclusion of extra tests on the 304 stainless steel and on fusion welds of the age-hardenable nickel base alloys. The latter tests were believed to be necessary to interpret the test data and to better understand the fusion weld properties.

5. APPARATUS

The test apparatus consists of four universal testing machines (30,000 to 400,000 lb. maximum capacities), four hydraulic test beds (50,000 lb. capacity), five liquid hydrogen cryostats, seven liquid nitrogen cryostats and accessory equipment such as cryo-extensometers, optical measuring systems, temperature recorders, etc. Descriptions of the apparatus for tensile testing may be found in Reference 4, for fatigue testing in Reference 1 and crack propagation testing in Reference 2.

6. EXPERIMENTAL RESULTS

Tensile, notched tensile, and fusion weld tensile data on Type 304 stainless steel, 18% nickel steel, Hastelloy B, Type 718 nickel alloy and 7039-T6 aluminum are reported in Tables 5, 6, 7, 8 and 9, respectively. These tables include 0.2 per cent yield strengths, tensile strengths, elongations, proportional limits, elastic moduli, hardness values of fractured specimens, notched (K_t of 6.3 and 19) tensile strengths, fracture toughness (K), and notched/unnotched tensile strength ratios on the parent metal and tensile strengths, elongations, hardness values, and joint efficiencies of butt fusion welded specimens. The data are reported for four test temperatures: 75°, -100°, -320°, and -423°F. The stress concentration factor (K_t) of each individual notched specimen was calculated and is reported in parenthesis with the notched tensile data. The fracture toughness (K) values were calculated from the equation $K^2 = \pi a \sigma^2$, where a is one-half of the initial crack (notch) length and σ is the gross stress (Ref. 8). It should be noted that the fracture toughness values reported in Tables 5 through 9 were calculated from initial crack (notch) lengths and not the critical crack lengths (the crack lengths at onset of rapid failure). Therefore, the values reported are K values, not K_C values, and as such are generally conservative.

Cross-tension and tensile-shear strengths and resulting tension/shear ratios obtained on individaul resistance spot welds are reported in Tables 10 through 14. Tests were performed at 75°, -100°, -320° and -423°F on Type 304 Stainless Steel, 18% nickel maraging steel, Hastelloy B, Type 718 nickel base alloy and 7039-T6 aluminum.

The high-stress, low-cycle fatigue data on 18% nickel maraging steel, Hastelloy B, Type 718 Nickel alloy, 7039-T6 aluminum and René 41 alloys are reported in Tables 15 through 19. Fatigue tests were performed at 75°, -320° and -423°F.

Results of a statistical reduction and analysis of the yield and tensile strength data on parent metal, tensile strength data on simple butt fusion welds, and cross-tension and tensile-shear data on individual resistance spot welds are given in Tables 20 through 23.

The results of crack propagation tests are reported in Tables 24 through 45. Crack propagation tests were conducted at 75° and -320°F. Data reported include initial and critical crack lengths, critical loads, gross and net stresses, fracture toughness (K_c), and strain energy release rate (G_c) values. Tables 24 through 31 report the basic crack propagation data on Type 304 stainless steel, 18% nickel maraging steel, Type 718 nickel alloy, Hastelloy B, René 41, 7039-T6 and 2219-T81 aluminum, and titanium 6Al-4V ELI alloy. Tables 32 through 34 give the results of a study on the effect of initial notch length on the crack propagation properties of Type 310 stainless steel, Type 718 nickel alloy and 2219-T81 aluminum alloy. The effects of specimen width on the crack propagation properties of Type 304 stainless steel, 18% nickel maraging steel, Type 718 nickel alloy, Hastelloy B, Rene 41, 7039-T6 and 2219-T81 aluminum, and titanium-6Al-4V ELI alloys are given in Tables 35 through 42. Tables 43 through 45 give the results of a study on the effects of loading rate on crack propagation properties of Type 310 stainless steel, Type 718 nickel, and 2219-T81 aluminum alloys.

7. STATISTICAL ANALYSIS OF DATA

A statistical analysis was performed on the alloys tested in this investigation. Results of the statistical analysis are reported for F_{ty}, F_{tu}, and weld tensile strengths for both the longitudinal and transverse directions, and cross-tension and tensile-shear strengths of individual resistance spot welds. The data for each of the test temperatures were analyzed.

Mean values, standard deviations, and 90- and 99-per cent probability (with 95-per cent confidence) values were obtained for the particular heats and lots of materials tested. The 90- and 99-per cent levels employed herein statistically correspond, respectively, to the "B" and "A" values as discussed in MIL-HDBK-5, March 1959 (Reference 5). The "B" and "A" values are not considered to be material design allowables because only one heat or lot of each material was tested which probably would not be fully representative of all material produced to the same specifications. Therefore, the 90- and 99-per cent levels may be considered to be "B" and "A" design allowables only for the particular heats tested.

For the purposes of this report, an "A" value will be considered to be that level which would be exceeded by at least 99 per cent of the population; i.e., the confidence is 95 per cent that 99 per cent of all the test data, for each test condition obtained from the tested heat and coil of material, would exceed "A" value. The "B" value is similarly defined for 90-per cent probability and 95-per cent confidence. The material property data were analyzed independently for each test condition. For F_{ty}, F_{tu}, and weld tensile strength, five test values were analyzed for each combination of three

materials, two grain directions, and four temperatures. For spotweld tensile and shear strengths, twenty test values were analyzed for each combination of four materials and four temperatures. In each case the sample standard deviation (S) was calculated from the following equation (Ref. 6).

$$s = \sqrt{\frac{\sum_{i=1}^{N} (X_i - \bar{X})^2}{N - 1}}$$

Where

N= number of test values,

X_i = test values, and

$$\bar{X} = \frac{1}{N} \sum_{i=1}^{N} X_i$$

The "A" and "B" values were evaluated by subtracting from $\bar{X}$ the product ks, where k is the applicable probability tolerance factor as follows:

$$X_B = \bar{X} - k_B s$$

$$X_A = \bar{X} - k_A s$$

Reference 7 contains tables of the one-sided tolerance factors for the normal distribution at the desired levels of probability and confidence. The assumption of normality in the analyses is justifiable on the basis of the small sample sizes. Previous investigations of strength properties having large sample sizes indicate that the distribution functions are often

slightly non-normal. In many cases, the log-normal distribution best describes the total population due to the influence of specification minimum requirements, quality control, etc. However, the use of non-normal distribution functions with small sample sizes where the population distribution is not definitely known may lead to erroneous results. The nowmal or Gaussian distribution function was therefore adopted for the analysis of the data herein.

The data were coded for and analyzed on an IBM 7090 digital computer. The results of the statistical analysis are presented in Tables 20-23. Included in Tables 20-23 are the means, standard deviations, and "A" and "B" values. An effort was made to indicate possible misleading values resulting from the statistical study. In general, for mechanical property data of engineering materials, the "A" value should exceed 80 per cent of the mean. Those "A" values given in Tables 20-23 which did not exceed 80 per cent of the mean are indicated by means of an asterisk. There are several possible explanations for the large standard deviations, and thus low "A" and "B" values, for the cases noted. There may have been too few of a number of test values, in which case additional testing would have to be performed to obtain better estimates of the population parameters. It may be that even with additional testing the dispersion of the data would remain large, in which case, it is possible that the data are not definite enough to permit a reasonable statistical evaluation. Large standard deviations may also be a result of the material, fabrication of the test specimen, or testing equipment and procedure. A more detailed discussion of standard deviations and design allowable values is given in Reference 1 and 2.

It is again emphasized that the "A" and "B" values as given in Tables 20-23 are not intended as design allowables for the materials but are, as defined previously, probability values based upon tests from one lot or one heat of each material.

8. DISCUSSION OF RESULTS

8.1 Mechanical Property Data

The mechanical property test data are reported in Tables 5 through 23. These tables include tensile, notched tensile, fusion weld tensile, spot weld tensile and shear, and axial fatigue data at room and cryogenic temperatures also, the results of a statistical analysis of these data are given. Tests were performed on Type 304 stainless steel, 18% nickel maraging steel, Hastelloy B, Type 718 nickel base alloy, and 7039-T6 aluminum alloy. In order to provide maximum clarity, the results will be discussed separately for each of the alloys.

Type 304 Stainless Steel - The properties of 50% cold rolled type 304 stainless steel were previously reported (Reference 1). However, there was an insufficient quantity of this material for the required fracture toughness testing. Therefore, another heat of material was procured, this time in the 70% cold rolled temper to make the strength/density ratio more competitive with that of cold rolled types 301 and 310 stainless steels (data reported in References 1 and 2).

Table 5 presents the mechanical property data on base metal, butt fusion welds and overlap resistance seam welds. These properties include yield and tensile strength, tensile elongations, proportional limits, elastic moduli, hardness and magnetic measurements,(the magnetic measurements to determine the percent of martensite phase present), and notched (K_t of both 6.3 and 19) tensile properties of the base metal. Fusion weld properties included tensile strength and elongations, joint efficiencies, and hardness and magnetic (martensitic) measurements. Resistance seam weld properties included tensile strength and joint efficiencies. Table 10 presents cross-

tension and tensile-shear strengths of individual resistance spot welds. The properties listed in Tables 5 and 10 were obtained at test temperatures of 75°, -100°, -320°, and -423°F.

The effects of decreasing test temperature on the mecahnical properties of the 70% cold rolled material are similar to those for the 50% cold rolled type 304 stainless steel (see Reference 1, Table 6, for comparison data). In general, the strengths, notched strengths and weld strengths, increased with reduction in test temperature. As would be expected, the 70% cold rolled material is stronger than the 50% cold rolled material which has 158 KSI F_{ty} and 180 KSI F_{tu} at room temperature. Ductility, as measured by total elongation over a two inch gage length, is about the same for the two tempers of material. Notched (K_t of 6.3 and 19)/ unnotched tensile strength ratios, which are used as an index of toughness, are similar for the longitudinal direction but are significantly less for the 70% cold rolled material in the transverse direction. This is attributed to the greater amount of cold work present. Properties of the fusion welds were similar for the two tempers, showing rather low joint efficiencies at room temperature but much improved efficiencies at cryogenic temperatures. In addition to the fusion weld data, properties of overlap resistance seam welds are included. These tests were performed to determine if improved joint efficiencies could be realized by this type of joint (an overlap resistance roll seam weld plus two rows of individual resistance spot welds as described in Reference 1 make up the typical transverse type of joint). As may be seen in Table 2, joint efficiencies are greater at room temperature for resistance seam weld joint than for the fusion weld joint; however at

-423°F, the reverse is true. Data on individual resistance spot welds (Table 10) show that the 70% cold rolled material possesses lower tension/shear ratios for the spot weld tests than does the 50% cold rolled material. This data, as well as the lower notched/unnotched tensile strength ratios in the transverse direction indicate that this particular heat and temper of type 304 stainless steel is not quite as tough as the 50% cold rolled material evaluated previously. It is believed, however, that this heat of 70% cold rolled type 304 stainless steel is sufficiently tough for structural applications at -423°F. Fracture toughness data on Type 304 stainless steel is presented in Table 24 and is discussed in the next section.

<u>18% Nickel Maraging Steel</u>- The mechanical properties of 18% nickel maraging steel (250 ksi strength grade) at room and cryogenic temperatures are given in Tables 6, 11 and 15. The material was evaluated in the aged condition (900°F, 3 hr., A.C.). The room temperature yield and tensile strengths are slightly greater and the elongation somewhat less than typical for this grade of sheet material (References 9 and 10). As would be expected, yield and tensile strengths increase with decrease in testing temperature. Also, proportional limits and elastic modulii increase at cryogenic temperatures. Elongations, however, suffer a decrease. Notched tensile strengths (for both K_t of 6.3 and 19) increase from 75° to -100°F and then decrease from -100° to -320°F. From -320° to -423°F, there is a very large decrease in notched tensile strengths. The resulting notched/unnotched tensile strength ratios, which are used as a measure of toughness, indicate a slight decrease in toughness at -320°F and a very significant decrease in toughness at -423°F.

Properties were obtained on fusion welds in two conditions. The first condition reported in Table 6 is for butt fusion weldments in aged material with no post welding treatment. The second condition (labeled aged weld in Table 6) consisted of butt fusion welding solution treated material followed by aging of the material and weldment. As expected, higher joint efficiencies are possessed by the aged weldments (second condition). However, slightly greater elongations are shown by the unaged weldments which also show continuous increases in strength from 75° to -423°F, whereas the aged weldments decreased in strength from -320° to -423°F. As discussed in references 1 and 2, a decrease in weld strength with reduction in test temperature is believed to be indicative of a decrease in toughness.

The tensile and shear properties of individual resistance spot welds of aged 18% nickel steel sheet material are given in Table 11. These test data also indicate a decrease in toughness at cryogenic temperatures, particularly at -423°F, since cross-tension strengths decrease from -320° to -423°F and because the tension/shear ratio decreases significantly at -320° and 423°F.

The axial fatigue properties of complex welded joints of 18% nickel steel are given in Table 15. The test data include the results of static and repeated loading tests at 75°, -320° and -423°F. The static test results show that the complex weld joints for both the longitudinal and transverse types of joints possess about 90% joint efficiency at room temperature and at -320°F. However, at -423°F, the joint efficiencies are only about 70-75% at -423°F. This is an indication of embrittlement of the joint at -423°F. The number of cycles to failure during repeated loading, with stress

levels of 75, 85 and 95% of the static joint strength, are similar for the 75° and -320°F tests. Repeated loading tests at -423°F are incomplete. The results of the mechanical property testing on the 18% nickel steel indicate that this alloy possesses good strength and toughness properties at 75° and -100°F. Strengths continue to increase at -320° and -423°F; however toughness is impaired at these temperatures, particularly at -423°F. It is believed, on the basis of the present results, that the 18% nickel maraging steel, 250 ksi grade in the aged temper, is sufficiently tough for structural applications from 75° to -320°F, but is not acceptable for use at -423°F.

Hastelloy B - The mechanical properties of 40% cold rolled Hastelloy B sheet material at room and cryogenic temperatures is given in Tables 7, 12, and 16. Interest was aroused in this alloy as a result of some tests performed early in the cryogenics test program at General Dynamics/Astronautics which showed this material to have fairly high room temperature strengths combined with excellent low temperature toughness (Ref. 11).

The room temperature yield and tensile strengths and elongation values for the longitudinal direction exceed those obtained in earlier tests (Ref. 11). However, no tests were performed on the transverse direction in the initial tests, therefore the large amount of directionality which is seen here was not previously noted. The directionality, particularly for the yield strengths, remains significant at cryogenic temperatures. Decrease in test temperature from 75° to -423°F results in continuous increases of the yield and tensile strengths, proportional limits, elastic modulii, elongations and notched (both for K_t of 6.3 and 19) tensile strengths. Resulting notched/unnotched tensile strength ratios indicate excellent toughness from 75° to

-423°F.

Properties of butt fusion welds (TIG welds with no post treatment) are also given in Table 7. Weld tensile strengths continuously increase from 75° to -423°F with resulting joint efficiencies of 65 to 75%. Elongations are fairly low at all test temperatures.

The tensile and shear properties of individual resistance spot welds at room and cryogenic temperatures are given in Table 12. Both the cross-tension and the tensile-shear strengths continuously increase from 75° to -423°F. The tension/shear ratio is fairly low at room temperature, but remains constant to -423°F. These data, as well as the notched tensile and fusion weld tensile data, indicate that 40% cold rolled Hastelloy B possesses excellent toughness from 75° to -423°F. Static tests on the complex welded joints of Hastelloy B (Table 16) show continuous increases in the joint strength from 75° to -423°F. This is another indication of the alloys good low temperature toughness. The repeated loading tests are presently being conducted.

Type 718 Nickel Alloy- Recent tests on type 718 nickel base alloy in aged and cold rolled and aged tempers have indicated that this alloy possesses very high strength properties combined with excellent low temperature toughness (References 12 and 13). Therefore type 718 was evaluated in the highest strength temper (30% cold rolled plus aged) that was commercially available. The mechanical properties are given in Tables 8,13, and 17.

As may be seen, this material possesses good strength, ductility and toughness properties from 75° to -423°F. Yield and tensile strengths, proportional limits, elastic modulii, elongations, and notched tensile strengths

increase from 75° to -423°F. Resulting notched/unnotched tensile strength ratios indicate excellent toughness to -423°F.

As was done with the 18% nickel steel, two different types of fusion weldments were evaluated for the 718 nickel base alloy. The first type consisted of butt fusion welding the cold rolled and aged material with no post welding treatment. The second type consisted of welding the cold rolled material followed by aging (1250°F, 8 hr., FC 20°F/Hr to 1150°F, hold for total of 18 hrs. aging time, FC) after welding. Significantly higher tensile strengths, and thus higher joint efficiencies, were obtained for the aged weldments. Fusion weld tensile strengths increased with decrease in test temperature for both types of fusion welded joints. Elongation values were low at all test temperatures for both the as welded and aged weldments. There was no indication of an appreciable decrease in toughness with reduction in test temperature.

The properties of individual resistance spot welds in cold rolled and aged type 718 nickel alloy sheet material at room and cryogenic temperatures are given in Table 13. Cross-tension strengths increased from 75° to -320°F and decreased slightly from -320° to -423°F. Tensile-shear strengths increased from 75° to -423°F. Resulting tensile/shear ratios decreased from 75° to -423°F; however the values were very high (0.50 to 0.65) at all test temperatures. The slight decrease in tension/shear ratio may be indicative of some decrease in toughness; however the very high values would seem to indicate, as did the notched tensile and weld tensile data, excellent toughness of this alloy from 75° to -423°F.

The static and fatigue properties of complex welded joints of the cold rolled and aged type 718 nickel alloy are given in Table 17. There is a continuous increase in the static joint strengths from 75° to -423°F.

Repeated loading tests indicate this alloy possesses excellent toughness at -320°F. Fatigue tests at 75° and -423°F are in progress.

7039 Aluminum Alloy- One of the recently developed weldable 7000 series aluminum alloys, 7039, was evaluated in the artificially aged (-T6) temper. Mechanical properties at room and cryogenic temperatures are given in Tables 9, 14 and 18. Room temperature properties are typical of the alloy. Yield and tensile strengths, proportional limits, elastic modulii, and notched (K_t= 6.3) tensile strengths continuously increased from 75° to -423°F. There was, however, only a very small increase in the notched tensile strengths from -320° to -423°F so that resulting notched (K_t= 6.3) unnotched tensile strength ratios decreased considerably from -320° to -423°F. The sharp notched (K_t= 19) tensile strengths increased from 75° to -100°F and and then decreased from -100°F to -320°F, with a large decrease in the notched (K_t = 19) / unnotched tensile strength ratios from -100° to -320°F. Elongation values continuously increased from 75° to -320°F and then decreased from -320° to -423°F. The elongation and notched (K_t=6.3) data indicate that 7039-T6 is tough at -320°F but decreases in toughness at -423°F, whereas the sharp notched (K_t=19) data indicate a severe decrease in toughness from -100° to -320°F.

The tensile strengths of fusion welds continuously increase from 75° to -320°F and then decrease from -320° to -423°F. Resulting joint efficiencies remain quite high to -320°F but undergo a severe decrease at -423°F. Weld elongations remain rather uniform from 75° to -320° and then decrease sharply from -320° to -423°F. These data seem to indicate that 7039-T6 weldments remain tough to -320°F but experience a severe decline of toughness from -320° to -423°F.

The properties of individual resistance spot welds of 7039-T6 sheet material are given in Table 14. Cross-tension strengths and tensile/shear ratios continuously decline from 75° to -423°F. The largest decrease in the tension shear ratio results from -100° to -320°F. These data indicate that the toughness of 7039-T6 decreases with decrease in test temperature, particularly between -100° and -320°F.

The results of static and repeated loading tests on large, butt fusion welded joints of 7039-T6 aluminum from 75° to -423° are given in Table 18. As may be seen from the test data, there is little or no increase in joint strength with decrease in test temperature. Also, there is a large amount of scatter in the test results for the repeated loading tests at -320° and -423°F. These data are indicative of decreased toughness at -320° and -423°F for the 7039-T6 aluminum alloy.

<u>Rene 41 Alloy-</u> The results of static and repeated loading tests on complex welded joints of René 41 alloy are given in Table 19. Test data on transverse joints at 75°, -320°, and -423°F are reported. These tests were performed to complete the fatigue test data on the René 41 alloy. The fatigue test data for the longitudinal joints are reported in Reference 2. As was true for the longitudinal test data, the static and repeated loading data for the transverse joints indicate René 41 possesses good low temperature toughness.

8.2 Crack Propagation Data

Fracture Concept

The most popular fracture concept used at present was principally developed by Irwin. This concept is closely related to Griffith's theory, but having an important difference in that the rate of energy dissipation is not assumed to be a constant in Irwin's Theory. The Irwin, or generally called the fracture mechanics, concept, analyzes the fracture in terms of the locally elevated stress field around the crack tip. Its connection to the Griffith concept is shown later by a relationship between the strain energy release rate, denoted by G, and the stress intensity factor, designated by K, near the crack edge. K is essentially a scale factor which denotes the magnitudes of the stress at a given point ahead of the crack tip. The relationship between K and G is:

$$K^2 = EG \text{ (for plane stress)}$$

or

$$K^2 = \frac{EG}{1-\;^{2}} \text{ (for plane strain)}$$

where E = Young's modules

and ν = Poisson's ratio

K can be calculated from:

$$K = \sigma_g \sqrt{W \operatorname{Tan} \frac{\pi a}{W}}$$

where σ_g = Gross stress at the end of the specimen in ksi

or

σ_g = Applied load divided by the gross cross-sectional area of the specimen.

W = Width of specimen in inches.

a = Instantaneous crack length (inches), corresponding to σ_g,

thus G can be expressed by:

$$\sigma_g^2 \; W \tan \frac{\pi a}{W} = EG,$$

or

$$\sigma_g = \sqrt{\frac{EG}{W \tan \frac{\pi a}{W}}}$$

If $\tan \frac{\pi a}{W}$ is replaced by $\frac{\pi a}{W}$ for the first approximation, the above equation becomes

$$\sigma_g = \sqrt{\frac{EG}{\pi a}}$$

which has the form of the original Griffith equation.

At the on-set of unstable fracturing or rapid crack propagation the stress intensity factor attains a critical value K_c which is directly related to G_c. The critical stress intensity factor K_c can be calculated by the following equation:

$$K_c = \sigma_{gc} \sqrt{W \tan \frac{\pi a_c}{W}}$$

where

K_c = critical crack intensity factor in the units of ksi$\sqrt{\text{in.}}$

σ_{gc} = critical gross stress applied at the end of the tensile specimen at the onset of rapid crack propagation, in the unit of ksi.

or

σ_{gc} = critical load divided by gross critical cross-section

W = width of the specimen in inches.

a_c = half of the critical crack length in inches

In the equations for calculating the normal or critical stress intensity factors, K or K_c, plastic deformation at the crack tip is not included. Irwin proposed the use of the plastic zone size at the crack tip to correct for the plastic deformation in the fracture intensity factors, K or K_c. However the equation without the plastic flow correction is a little more conservative.

It has been found experimentally that for low and moderate values of crack length (2a) to specimen width (W) ratio ($\frac{2a}{W} < 0.35$) the stress in the unnotched region would be the same as the average applied stress, σ_g. However, when $\frac{2a}{W}$ is appreciable (>>0.35) the average stress level in the uncracked region will approach the net fracture stress, σ_n. Then the net fracture stress, or the net section stress, σ_n, becomes very useful. The net fracture stress σ_n may be calculated from the following equation:

$$\sigma_n = \frac{P}{t(W-2a)}$$

where

σ_n = net fracture stress, ksi

p = applied load in 1,000 lbs.

t = thickness of specimen in inches

At critical load, P_c, one has

$$\sigma_{nc} = \frac{Pc}{t(W-2a_c)},$$

where

σ_{nc} = critical net fracture stress, ksi.

Although G_c has been used as a scale for comparison, or selection, of toughness of the materials, both G_c and K_c are sensitive to test temperature,

width and thickness of the specimen, initial crack length and load rate or stress rate. The effect of initial notch lengths on K_c & G_c of most of the materials studied in this investigation are listed in Tables 32 through 34, the effect of specimen width, in tables 24 through 31 and tables 35 to 42 and the effect of load rates in tables 43 through 45.

Fracture testing is performed with center slotted specimens which have 30% to 40% of specimen width and are loaded in tension in a universal tensile testing machine. This is called the static testing of crack propagation. Crack extension is measured up to the on-set of rapid crack propagation. The initial length of the man-made crack is machined such that some amount of slow crack growth would occur before the on-set of rapid crack propagation. The only test data which is needed to be taken is the instantaneous load and corresponding crack lengths. These data will be used to calculate K_c, G_c and σ_n. The load rate in the tests was 0.015 in/min, if it is not specified otherwise.

<u>Static Tests</u>

Test results of static crack propagation in the following two general categories will be discussed briefly in this section:

(1) Crack propagation properties at 75°F and -320°F

(2) Effect of specimen geometry, (initial notch length and width) and test condition (loading rates at 75°F and -320°F).

Table 24 through 31 shows the crack propagation properties (K_c and G_c) in both longitudinal and transverse grain directions, and at test temperature of 75°F and -320°F.

Generally both K_c and G_c in longitudinal grain direction are higher in magnitude than that in transverse grain direction at the same test temperature, except K_c & G_c for titanium-6Al-4V at -320°F and G_c for

René 41 at 75° σ_g and σ_n are higher too, in magnitude, in longitudinal grain direction than in the transverse except for σ_g at -320°F for Ti-6Al-4V and σ_g at 75°F for René 41.

When temperature is lowered from 75°F to -320°F, K_c and G_c increase except for the titanium 6Al-4V alloy in the ELI grade, 7039-T6 aluminum alloy and the 18% Ni maraging steel. The critical loads for these three metals are lower in value at -320°F than at 75° F, but the critical crack length at -320°F are about the same or longer than that at 75°F. Therefore these three metals are less tough-resistant to fracture at 320°F than at 75°F according to the data thus far available.

In the results of the effect of initial notch length from 0.75" to 1.75" (table 32 to table 34), at both 75°F and -320°F, both K_c and G_c decrease in magnitude with the increase in initial notch lengths. This is of course attributed to the decrease in critical load and increase in critical crack length.

Tables 24 through 31 and tables 35 through 42 show the effect of specimen width from 4 inch to 2 inch, for a constant initial notch length to specimen width ratio of 30%. It is observed that the wider the specimen, the higher the G_c and K_c, except for the Ti-6Al-4V alloy at -320°F and 18% Ni maraging steel at both 75°F and -320°F.

There is no effect of load rates (table 43 to table 45) on K_c and G_c for 310 stainless steel at 75° or -320°F. For the 718 nickel alloy at 75°F K_c and G_c are about equal for 0.01 and 1.0 in/min. load rates but lower in value at 10.0 $\frac{\text{in.}}{\text{min.}}$ for 75°F. However for 2219-T81 aluminum alloy K_c and G_c are about the same in magnitude at 1.0 and 10.0 $\frac{\text{in.}}{\text{min.}}$ load rates but higher, at 0.01 in/min. at 75°F test temperature.

At -320°F the higher the load rates, the lower the K_c and G_c values.

This is consistantly true for 310 stainless steel, 718 nickel alloy and 2219-T81 aluminum alloy.

A better observation for a general trend and a more thorough analysis of the test data will be done when the complete data is available. More definite conclusions can then be made.

9. FUTURE WORK

During the next reporting period it is anticipated that the remaining test specimens will be fabricated. It is expected that all of the mechanical property testing and about 80% of the fracture toughness testing will be completed by the end of the next quarter. In addition, metallographic studies, hardness determinations, and analysis and evaluation of the test data will be made. Primary emphasis will be placed upon the analysis of the crack propagation data in order to help define the effects of temperature, specimen configuration, material thickness, loading rate, etc. on the fracture toughness characteristics of high strength sheet materials. The program schedule is given in Figure 1.

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FIGURE 1.

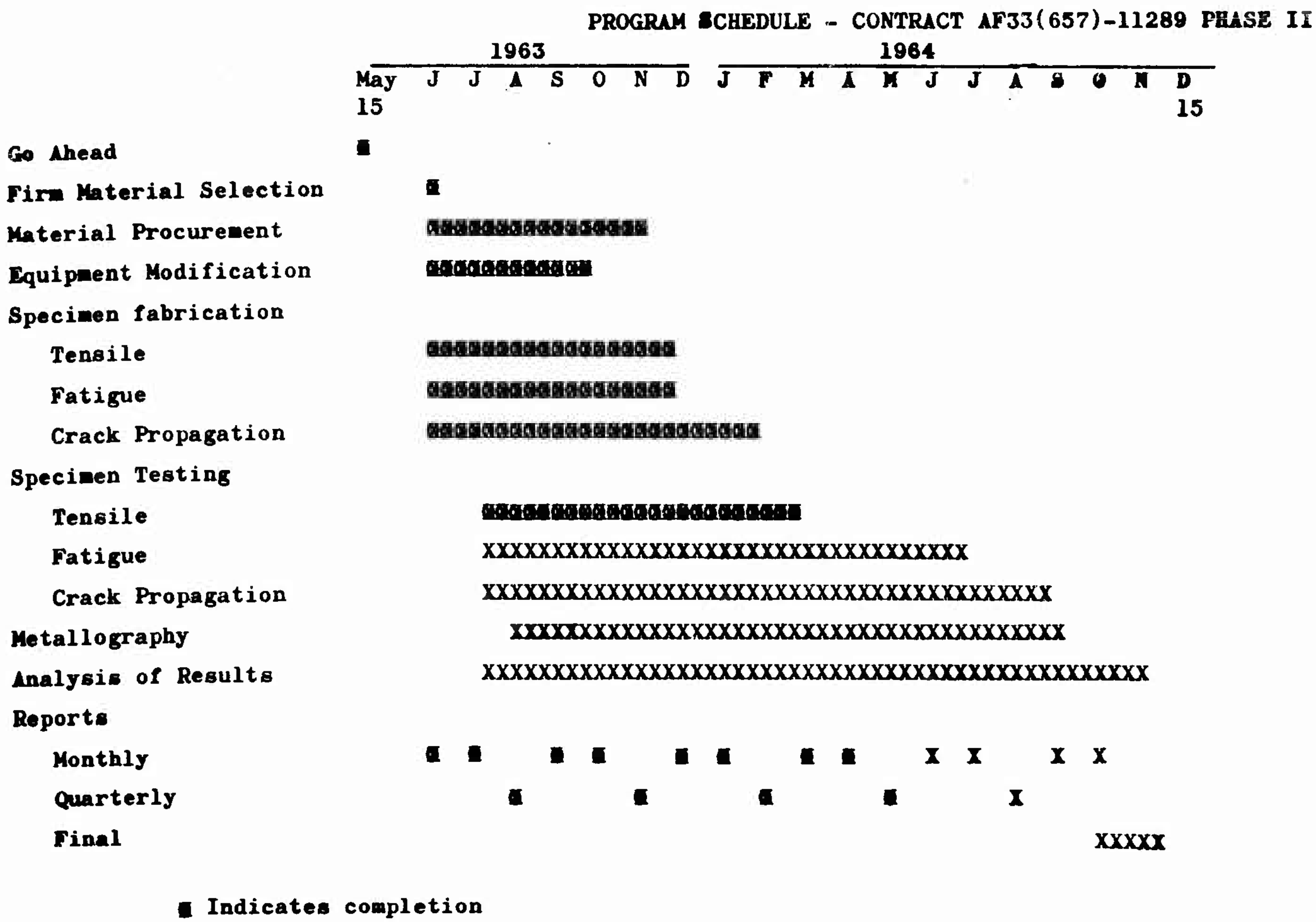
PROGRAM SCHEDULE - CONTRACT AF33(657)-11289 PHASE II
1963
1964
May 15
J J A S O N D J F M A M J J A S O N D 15
Go Ahead
Firm Material Selection
Material Procurement
Equipment Modification
Specimen fabrication
Tensile
Fatigue
Crack Propagation
Specimen Testing
Tensile
Fatigue
Crack Propagation
Metallography
Analysis of Results
Reports
Monthly
Quarterly
Final
Indicates completion

Table 1. HISTORY AND CHEMICAL ANALYSIS OF TEST MATERIALS

Alloy	Type 304 Stainless Steel	18% Nickel Maraging Steel	Rene 41 Nickel Alloy	Hastelloy B Nickel Alloy	718 Nickel Alloy
Temper	70% cold rolled	Aged (900°F, 3 Hr., A.C.)	Aged(1400°F, 16 hours)	40% cold rolled	30% cold rolled + aged
Gage (in.)	0.020	0.025	0.020	0.020	0.025
Supplier	Allegheny-Ludlum Steel Corp.	Latrobe Steel Company	Union Carbide Stellite	Wallingford Steel Co.	Huntington, Div. of INCO
Heat No.	94997	C56858	T2-8259	B3-2330	6807EV
Specification	GD/AO-71004	Latrobe Marvac 18	AMS 5545	-	-
Hardness (15N)	81.6	85.8	80.0	81.8	84.6
Chemistry(Wt.%)					
Al	-	0.11	1.50	-	0.35
B	-	0.004	-	-	-
C	0.053	0.03	0.10	0.01	0.04
Co	-	8.00	11.08	1.04	-
Cu	0.13	-	-	-	0.05
Cr	18.44	-	19.27	0.15	18.80
Fe	Bal.	Bal.	2.51	4.76	18.84
H	-	-	-	-	-
Mg	-	-	-	-	-
Mn	1.06	0.03	0.006	0.46	0.16
Mo	0.17	4.75	9.68	26.40	3.12
N	-	-	-	-	-
Ni	9.57	18.34	Bal.	Bal.	52.29
O	-	-	-	-	-
P	0.008	0.004	-	0.001	-
S	0.015	0.008	0.009	0.020	0.007
Si	0.48	0.05	0.20	0.31	0.32
Sn	-	-	-	-	-
Ti	-	0.49	3.23	-	0.85
V	-	-	-	0.29	-
Zn	-	-	-	-	-
Zr	-	0.03	-	-	-
Cb+Ta	-	-	-	-	5.15

Table 1 (Cont'd.)

HISTORY AND CHEMICAL ANALYSIS OF TEST MATERIALS

Alloy	7039 Alum. Alloy	2219 Alum. Alloy	Titanium 5 Al-2.5Sn ELI	Titanium 6Al-4V ELI	Type 310 Stainless Steel
Temper	-T6	-T81	Annealed	Annealed	75% cold rolled
Gage (in.)	0.063	0.063,0.125	0.025,0.050, 0.090	0.025	0.010
Supplier	Kaiser Alum. Company	Aluminum Co. of America	Repuplic Steel Corp.	Titanium Metals Corp. of America	Washington Steel Corp.
Heat No.	-	-	3960420	D-2133	43631
Specification	-	Mil A 8920	GD/AO-71010	Internal	-
Hardness (15N)	59.6	54.3		77.8	
Chemistry (Wt.%)					
Al	Bal.	Bal.	5.47	6.1	-
B	-	-	-	-	
C	-	-	0.032	0.025	0.25
Co	-	-	-	-	-
Cu	0.06	5.8	-	-	-
Cr	0.17	-	-	-	25.00
Fe	0.15	0.10	0.14	0.13	Bal.
H	-	-	0.008	0.007 0.010	-
Mg	2.51	0.01	-	-	-
Mn	0.18	0.29	0.01	-	2.00
Mo	-	-	-	-	-
N	-	-	-	-	-
Ni	-	-	-	-	20.50
O	-	-	-	0.11	-
P	-	-	-	-	0.045
S	-	-	-	-	-
Si	0.16	0.1	-	-	1.50
Sn	-	-	2.50	-	-
Ti	0.09	0.066	Bal.	Bal.	-
V	-	-	-	4.1	-
Zn	4.14	-	-	-	-
Zr	-	-	-	-	-
Cb+Ta	-	-	-	-	-

Table 2. INERT-ARC STRAIGHT LINE FUSION WELD SCHEDULES

MATERIAL	FILLER	AMPS*	VOLTS	SPEED (in./min.)	BACKUP GAS (Ft^3/Hr.)	TORCH GAS (Ft^3/Hr.)	CLAMP PRESSURE (PSI)	BACKUP BAR (ROOM TEMP)	ELECTRODE (TUNGSTEN 2% THORIATED) (in.) **
18% Nickel Maraging Steel (0.025 in.)	None	14	18	10	He/50	He/50	40	Stainless Steel	0.062
718 Nickel Alloy (0.025 in.)	None	12	16	9	He/50	He/50	40	Stainless Steel	0.062
Hastelloy B Nickel Alloy (0.020 in.)	None	8	25	8	He/50	He/50	40	Stainless Steel	0.062

* Direct current, straight polarity

** All electrodes tapered 30°

Table 3. RESISTANCE SPOT WELD SCHEDULES

MATERIAL	ELECTRODE FORCE (Lb.)	HEAT (CYCLES)	COOL (CYCLES)	SQUEEZE (CYCLES)	HOLD (CYCLES)	WELD (% HEAT)	ELECTRODES (TOP AND BOTTOM) CLASS	FACE(IN)	RADIUS(IN)
7039-T6 Aluminum Alloy (0.063 in.)	1100 Initial 2400 Final	4	2	50	40	68	I	1/2	8
18% Nickel Maraging Steel (0.025 in.)	1700	5	-	50	40	87	III	3/8	6
718 Nickel Alloy (0.025 in.)	1000	10	-	40	40	74	III	5/8	8
Hastelloy B Nickel Alloy (0.020 in.)	1000	10	-	40	40	68	III	5/8	8

Table 4. RESISTANCE SEAM WELD SCHEDULES *

MATERIAL	ELECTRODE FORCE (LB)	HEAT (CYCLES)	COOL (CYCLES)	WELD (% HEAT)	SPEED (IN/MIN)	ELECTRODES (TOP & BOTTOM)				
						CLASS	FACE (IN.)	DIA. (IN.)	RADIUS (IN.)	SPOTS PER INCH
Rene 41 Nickel Alloy (0.020 in.)	1500 Buck 3000 Weld	10	1	40	8	III	3/8 & 1/2	12	6	14
18% Nickel Maraging Steel (0.025 in.)	32	2	7	89	Low 4	IIIA	3/8	10	6	-
718 Nickel Alloy (0.025 in.)	32	2	7	88	Low 4	IIIA	3/8	10	6	-
Hastelloy B Nickel Alloy (0.020 in.)	32	2	7	87	Low 4	IIIA	3/8	10	6	-

* Taylor-Winfield Welder, 125 KVA Transformer.

Table 5.

MECHANICAL PROPERTIES OF 70 PERCENT COLD ROLLED TYPE 304 STAINLESS STEEL
0.020 In. Sheet, Allegheny-Ludlum Steel Corp., Heat No. 94997

Test Temp (°F)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness (15N) Reduced Section	Hardness (15N) Fractured Edge	% Martensite Reduced Section	% Martensite Fractured Edge
75	Long.	170	190	3.5	58.3	25.7	81.3	81.4	2	6
	Long.	172	192	2.5	59.6	26.0	81.7	82.6	3	3
	Long.	171	190	2.5	55.1	26.1	82.1	82.1	2	5
	Long.	176	192	2.5	63.0	26.4	82.1	82.8	1	4
	Long.	176	193	2.5	58.7	25.3	82.0	82.3	2	6
	Avg.	173	191	2.7	58.9	25.9	81.8	82.2	2	5
75	Trans.	169	207	5.0	55.6	27.6	81.6	81.9	1	4
	Trans.	170	209	5.0	57.2	28.1	81.8	82.4	1	3
	Trans.	172	208	5.0	57.7	28.2	82.3	82.3	2	5
	Trans.	169	208	5.0	59.8	27.4	81.9	82.1	2	5
	Trans.	173	211	4.5	63.2	28.8	82.1	82.2	2	9
	Avg.	171	209	4.9	58.7	28.0	81.9	82.2	2	5
-100	Long.	191	212	11.0	97.4	26.7	82.1	82.3	4	6
	Long.	188	216	9.0	94.3	26.9	82.3	82.7	2	11
	Long.	189	214	8.5	98.1	26.4	81.6	82.4	2	5
	Long.	193	212	8.5	101.	27.4	81.8	82.6	2	4
	Long.	181	211	11.0	92.4	27.1	82.4	83.0	3	4
	Avg.	188	213	9.6	96.6	26.9	82.0	82.6	3	6
-100	Trans.	192	234	7.5	94.0	29.1	81.8	82.4	4	3
	Trans.	201	235	7.0	103.	29.4	81.9	82.4	3	6
	Trans.	196	233	7.5	96.2	28.3	82.4	82.7	2	6
	Trans.	188	232	7.5	96.1	28.7	82.1	83.1	3	9
	Trans.	189	227	6.0	99.3	28.8	82.1	83.0	4	11
	Avg.	193	232	7.1	99.7	28.9	82.1	82.7	3	7

Table 5. (Cont.)

Test Temp. (°F.)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness (15N) Reduced Section	Hardness (15N) Fractured Edge	% Martensite Reduced Section	% Martensite Fractured Edge
-320	Long.	197	273	29.0	101	29.1	84.1	85.2	2	94
	Long.	209	273	29.0	113	29.0	84.3	85.1	2	96
	Long.	207	273	28.0	107	28.8	83.7	83.9	3	97
	Long.	208	280	29.0	107	29.7	84.2	84.7	2	98
	Long.	218	282	28.5	112	28.8	84.4	84.7	1	98
	Avg.	**208**	276	28.6	108	29.1	84.1	84.7	2	97
-320	Trans.	218	268	22.0	114	30.1	84.3	84.7	2	96
	Trans.	212	271	22.0	111	30.3	83.7	84.0	2	97
	Trans.	215	272	21.5	102	29.6	84.4	84.8	4	98
	Trans.	212	273	22.0	107	30.2	84.3	85.1	3	94
	Trans.	212	271	24.0	113	29.8	83.9	84.3	2	98
	Avg.	214	**271**	22.9	109	30.0	84.1	84.6	3	97
-423	Long.	212	277	1.5	137	31.3	82.3	82.3	2	3
	Long.	234	298	1.5	146	30.4	83.1	83.6	3	7
	Long.	220	292	1.5	139	30.3	82.4	83.1	3	6
	Long.	226	297	2.0	143	30.7	81.8	82.4	2	2
	Long.	-	289	1.5	-	-	83.0	84.3	1	3
	Long.	236	301	2.5	148	29.6	82.4	83.0	2	3
	Avg.	226	292	1.8	143	30.5	82.5	83.1	2	4
-423	Trans.	227	314	1.0	141	31.2	82.3	82.4	2	7
	Trans.	220	315	1.5	137	31.7	83.1	83.6	2	10
	Trans.	225	314	2.0	138	31.6	83.1	83.7	2	4
	Trans.	231	311	1.0	149	30.3	82.6	82.9	1	6
	Trans.	227	309	1.0	143	30.5	81.9	82.4	1	3
	Avg.	226	**313**	1.3	142	31.1	82.6	83.0	2	6

Table 5.(Cont'd.)

Test Temp. (^oF)	Direction	Notched Tensile Strength(K_t=6.3) (KSI)	Fracture Tough. K (KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Notched Tensile Strength(K_t=19) (KSI)	Fracture Tough K (KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio
75	Long.	209 (6.3)	58.7		164 (19.4)	79.4	
	Long.	217 (6.4)	60.9		171 (19.6)	82.6	
	Long.	218 (6.4)	61.1		168 (19.6)	81.4	
	Long.	206 (6.4)	57.8		177 (19.5)	85.5	
	Long.	208 (6.4)	58.4		162 (19.6)	78.4	
	Avg.	212	59.4	1.10	168	81.5	0.88
75	Trans.	178 (6.3)	49.9		173 (19.2)	83.6	
	Trans.	166 (6.3)	46.6		169 (19.2)	81.7	
	Trans.	169 (6.4)	47.4		154 (19.2)	74.4	
	Trans.	176 (6.3)	49.4		156 (19.2)	75.4	
	Trans.	179 (6.4)	50.2		163 (19.2)	78.8	
	Avg.	174	48.7	0.83	163	78.8	0.78
-100	Long.	232 (6.4)	65.2		197 (19.5)	95.2	
	Long.	231 (6.4)	64.9		184 (19.5)	89.0	
	Long.	231 (6.5)	64.9		188 (19.6)	90.9	
	Long.	234 (6.4)	65.8		196 (19.5)	94.7	
	Long.	228 (6.3)	64.1		180 (19.6)	87.0	
	Avg.	231	65.0	1.08	189	91.4	0.89
-100	Trans.	211 (6.3)	59.3		177 (19.2)	85.5	
	Trans.	194 (6.3)	54.5		184 (19.1)	89.0	
	Trans.	212 (6.3)	59.5		186 (19.2)	90.0	
	Trans.	198 (6.4)	55.6		183 (19.2)	88.4	
	Trans.	201 (6.4)	56.5		190 (19.1)	91.8	
	Avg.	203	57.1	0.88	184	88.9	0.79

Table 5 (Cont'd.)

Test Temp. (°F)	Direction	Notched Tensile Strength(K_t=6.3) (KSI)	Fracture Tough. K (KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Notched Tensile Strength(K_t=19) (KSI)	Fracture Tough. K (KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio
-320	Long.	277 (6.4)	77.8		227 (19.4)	110	
	Long.	274 (6.4)	77.0		238 (19.6)	115	
	Long.	274 (6.3)	77.0		244 (19.6)	118	
	Long.	278 (6.3)	78.1		232 (19.6)	112	
	Long.	281 (6.3)	79.0		236 (19.6)	114	
	Avg.	277	77.8	1.00	235	114	0.85
-320	Trans.	244 (6.4)	78.6		238 (19.2)	115	
	Trans.	247 (6.4)	79.4		212 (19.2)	102	
	Trans.	248 (6.3)	79.6		226 (19.1)	109	
	Trans.	242 (6.4)	78.0		219 (19.2)	106	
	Trans.	246 (6.4)	79.2		223 (19.1)	108	
	Avg.	245	79.0	0.90	224	108	0.83
-423	Long.	321 (6.3)	90.2		241 (19.5)	116	
	Long.	316 (6.4)	88.7		237 (19.5)	114	
	Long.	307 (6.4)	86.2		224 (19.6)	108	
	Long.	312 (6.4)	87.7		221 (19.6)	107	
	Long.	311 (6.4)	87.4		227 (19.6)	110	
	Avg.	313	88.0	1.08	230	111	0.79
-423	Trans.	269 (6.3)	75.6		227 (19.2)	110	
	Trans.	274 (6.4)	77.0		234 (19.1)	114	
	Trans.	278 (6.4)	78.1		218 (19.2)	105	
	Trans.	282 (6.3)	79.2		219 (19.2)	106	
	Trans.	277 (6.3)	77.8		241 (19.2)	116	
	Avg.	276	77.6	0.88	228	110	0.73

Table 5 (Cont'd.)

Test Temp. (^{o}F)	Direction	Fusion Weld Tensile Strength (KSI)	Fusion Weld Elongation (%)	Fusion Weld Joint Efficiency (%)	Hardness (15-N) Heat Affected Zone	Hardness (15-N) Weld	% Martensite Heat Affected Zone	% Martensite Weld	Resist. Seam Weld Tensile Strength (KSI)	Resist. Seam Weld Joint Efficiency (%)
75	Long.	100	2.5		81.1	56.3	1	1	141	
	Long.	96.2	1.5		82.3	54.2	1	3	140	
	Long.	94.7	1.0		82.1	57.1	2	2	140	
	Long.	100	2.0		82.4	55.8	3	1	142	
	Long.	100	1.5		81.5	54.4	1	1	141	
	Avg.	98.2	1.7	51	81.9	55.6	2	2	141	74
75	Trans.	102	2.5		81.4	56.2	1	1	150	
	Trans.	102	2.0		82.3	55.8	2	3	154	
	Trans.	102	2.0		81.9	54.3	2	1	146	
	Trans.	100	2.0		81.7	51.1	2	1	151	
	Trans.	103	3.0		81.4	53.2	2	1	151	
	Avg.	102	2.3	49	81.7	54.1	2	1	150	72
-100	Long.	174	2.0		81.4	67.2	2	1	194	
	Long.	177	2.0		82.7	68.3	2	2	190	
	Long.	178	2.0		82.3	71.2	3	2	193	
	Long.	177	2.5		81.1	66.4	3	1	186	
	Long.	179	3.0		81.6	69.3	3	3	192	
	Avg.	177	2.3	83	81.8	68.5	3	2	191	90
-100	Trans.	180	2.5		81.0	66.2	3	2	187	
	Trans.	179	2.0		81.4	64.3	2	3	204	
	Trans.	181	1.5		83.0	67.2	2	3	203	
	Trans.	180	1.5		82.2	61.4	2	1	202	
	Trans.	180	2.5		81.9	67.8	3	3	186	
	Avg.	180	2.0	78	81.9	65.4	2	2	196	85

Table 5 (Cont'd.)

Test Temp. (°F)	Direction	Fusion Weld Tensile Strength (KSI)	Fusion Weld Elongation (%)	Fusion Weld Joint Efficiency (%)	Hardness (15-N) Heat Affected Zone	Hardness (15-N) Weld	% Martensite Heat Affected Zone	% Martensite Weld	Resist. Seam Weld Tensile Strength (KSI)	Resist. Seam Weld Joint Efficiency (%)
-320	Long.	244	2.5		81.4	74.3	3	1	233	
	Long.	243	1.5		81.7	76.2	3	3	230	
	Long.	240	2.0		82.3	76.8	2	2	228	
	Long.	244	3.0		82.3	77.4	2	2	231	
	Long.	242	2.0		83.0	79.2	2	1	235	
	Avg.	243	2.2	88	82.1	76.8	2	2	231	84
-320	Trans.	249	3.0		81.6	76.9	3	4	242	
	Trans.	251	2.5		82.1	78.2	3	4	251	
	Trans.	248	2.0		81.8	81.3	3	3	228	
	Trans.	249	2.0		81.3	80.2	4	4	240	
	Trans.	250	2.0		81.9	80.0	6	4	242	
	Avg.	249	2.3	92	81.7	79.3	4	4	241	89
-423	Long.	262	3.0		82.1	77.4	3	2	224	
	Long.	264	3.5		81.7	79.3	2	1	226	
	Long.	264	3.0		81.4	78.9	2	2	226	
	Long.	271	2.0		81.0	80.4	4	3	234	
	Long.	266	2.5		82.1	79.6	3	1	237	
	Avg.	265	2.8	91	81.7	79.1	3	2	229	78
-423	Trans.	292	2.0		81.9	80.2	2	2	236	
	Trans.	294	2.0		82.4	80.3	4	2	229	
	Trans.	292	3.0		81.7	80.1	3	2	224	
	Trans.	287	3.5		82.3	79.4	5	4	234	
	Trans.	286	3.0		81.9	76.8	6	4	238	
	Avg.	290	2.7	93	82.0	79.4	4	3	232	75

Table 6

MECHANICAL PROPERTIES OF 18 PERCENT NICKEL MARAGING STEEL
(0.025 IN. SHEET, LATROBE STEEL CO., HEAT NO. C56858)

Test Temp. (°F)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness (15-N) Reduced Section	Hardness (15-N) Fractured Edge	Notched T.S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/Unnotched Tensile Ratio
75	Long.	279	285	4.0	169	25.6	88	89	308(6.3)	86.2	
	Long.	277	284	3.0	171	26.0	87	87	307(6.3)	86.0	
	Long.	276	283	4.0	168	26.0	86	87	306(6.3)	85.7	
	Long.	278	284	4.5	165	25.0	87	86	309(6.3)	86.5	
	Long.	274	281	4.0	164	26.0	86	87	307(6.3)	86.0	
	Avg.	277	283	3.9	167	25.7	87	87	307	86.0	1.08
75	Trans.	275	283	4.0	169	25.2	87	88	305(6.4)	85.4	
	Trans.	277	285	4.0	181	25.0	87	88	295(6.4)	82.6	
	Trans.	278	286	5.0	180	25.6	86	86	304(6.3)	85.1	
	Trans.	277	285	4.5	187	26.1	86	87	299(6.3)	83.7	
	Trans.	277	284	2.0	171	25.1	86	85	293(6.3)	82.0	
	Avg.	277	285	3.1	178	25.4	86	87	299	83.7	1.05
-100	Long.	298	304	1.5	257	26.7	88	88	338(6.3)	94.6	
	Long.	299	304	2.0	261	26.8	88	88	345(6.3)	96.6	
	Long.	279	303	2.0	258	26.5	86	87	347(6.3)	97.2	
	Long.	294	301	1.0	263	26.2	87	88	346(6.3)	96.9	
	Long.	296	307	1.5	267	24.5	86	86	342(6.3)	95.8	
	Avg.	293	304	1.6	261	26.1	87	87	344	96.3	1.13
-100	Trans.	301	310	1.5	261	27.5	87	87	344(6.3)	96.3	
	Trans.	303	310	2.0	253	26.7	87	88	338(6.3)	94.6	
	Trans.	305	314	2.0	264	26.7	86	88	349(6.3)	97.7	
	Trans.	301	309	2.0	260	26.2	86	88	337(6.3)	94.4	
	Trans.	301	313	2.0	255	25.9	86	89	321(6.3)	89.9	
	Avg.	302	311	1.9	259	26.6	86	88	338	94.6	1.09

Table 6 (Cont'd.)

Test Temp. (^oF)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness (15-N) Reduced Section	Hardness (15-N) Fractured Edge	Notched T. S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/Unnotched Tensile Ratio
-320	Long.	331	349	1.5	292	27.3	87	86	337(6.4)	94.4	
	Long.	340	354	1.0	293	28.0	87	88	336(6.4)	94.1	
	Long.	335	349	1.0	288	27.3	87	88	344(6.4)	96.3	
	Long.	338	352	1.0	288	28.7	87	86	367(6.4)	103	
	Long.	336	349	1.0	273	29.1	87	88	341(6.4)	95.5	
	Avg.	336	351	1.1	287	28.1	87	87	345	96.6	0.98
-320	Trans.	343	357	2.0	295	27.1	87	87	364(6.3)	102	
	Trans.	339	355	1.5	267	27.1	87	87	356(6.3)	99.7	
	Trans.	341	357	1.0	304	28.0	86	88	358(6.3)	100	
	Trans.	339	357	1.0	286	27.6	86	88	379(6.3)	106	
	Trans.	341	356	1.0	273	28.5	88	88	337(6.3)	94.4	
	Avg.	341	356	1.3	285	27.7	87	88	359	101	1.01
-423	Long.	386	398	1.0	312	28.4	87	86	277(6.3)	77.6	
	Long.	384	396	1.0	272	29.3	86	87	295(6.4)	82.6	
	Long.	387	397	1.0	309	28.7	87	87	267(6.3)	74.8	
	Long.	387	398	1.0	277	28.9	86	88	245(6.3)	68.6	
	Long.	387	397	1.5	279	28.2	86	87	243(6.3)	68.0	
	Avg.	386	397	1.1	290	28.7	86	87	265	74.2	0.67
-423	Trans.	388	402	1.5	295	27.3	86	86	244(6.3)	68.3	
	Trans.	388	402	1.5	274	28.1	88	88	251(6.4)	70.3	
	Trans.	388	402	1.5	315	27.5	86	88	268(6.3)	75.0	
	Trans.	385	389	0.0	300	28.3	87	86	284(6.3)	79.5	
	Trans.	392	395	0.0	301	28.4	87	88	266(6.3)	74.5	
	Avg.	388	398	0.9	297	27.9	87	87	263	73.6	0.66

Table 6 (Cont'd.)

Test Temp. (°F)	Direction	Notched T. S. (K_t = 19) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Weld T. S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
75	Long.	212 (18.6)	102		145	2.0		76	75
	Long.	217 (18.6)	104		144	2.0		79	75
	Long.	222 (18.6)	107		137	2.0		81	74
	Long.	214 (18.6)	103		142	2.0		76	76
	Long.	228 (18.6)	109		147	2.0		79	76
	Avg.	219	105	0.77	143	2.0	51	78	75
75	Trans.	217 (18.6)	104		140	2.0		79	76
	Trans.	198 (18.6)	95.0		143	2.5		79	76
	Trans.	216 (18.6)	104		145	1.5		77	77
	Trans.	203 (18.7)	97.4		138	2.0		78	76
	Trans.	199 (18.6)	95.5		143	2.0		78	74
	Avg.	207	99.4	0.73	142	2.0	50	78	76
-100	Long.	249 (18.6)	120		173	2.0		76	76
	Long.	225 (18.6)	108		169	2.0		77	76
	Long.	219)18.6)	105		173	1.5		75	76
	Long.	196 (18.6)	94.1		168	2.5		77	75
	Long.	220 (18.6)	106		172	2.0		76	76
	Avg.	222	107	0.73	171	2.0	56	76	76
-100	Trans.	188 (18.7)	90.2		163	2.5		80	78
	Trans.	189 (18.7)	90.7		164	2.0		80	76
	Trans.	199 (18.7)	95.5		164	2.0		81	75
	Trans.	206 (18.7)	98.9		164	2.0		76	77
	Trans.	213 (18.7)	102		166	2.0		78	78
	Avg.	199	95.5	0.64	164	2.1	53	79	77

Table 6 (Cont'd.)

Test Temp. (°F)	Direction	Notched T.S. (K_t = 19) (KSI)	Fracture Toughness $K(KSI\sqrt{in.})$	Notched/Unnotched Tensile Ratio	Weld T.S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15N	
								Heat Affected Zone	Weld
-320	Long.	181 (18.7)	86.9		217	2.5		76	72
	Long.	229 (18.7)	110		217	2.5		76	77
	Long.	171 (18.6)	82.1		220	2.5		77	76
	Long.	180 (18.7)	86.4		216	2.5		76	74
	Long.	191 (18.7)	91.7		212	2.5		76	76
	Avg.	190	91.2	0.54	216	2.5	62	76	75
-320	Trans.	167 (18.7)	80.2		212	2.5		81	74
	Trans.	194 (18.7)	93.1		211	2.5		78	77
	Trans.	208 (18.7)	99.8		203	2.5		76	77
	Trans.	226 (18.7)	108		213	2.5		76	76
	Trans.	178 (18.7)	85.4		209	2.5		78	78
	Avg.	194	93.1	0.55	210	2.5	59	78	77
-423	Long.	115 (18.7)	55.2		269	1.5		75	77
	Long.	130 (18.7)	62.4		261	1.5		76	77
	Long.	94.7 (18.7)	45.5		265	2.0		75	74
	Long.	122 (18.6)	58.6		267	2.0		75	77
	Long.	125 (18.6)	60.0		266	1.5		74	76
	Avg.	118	56.6	0.30	266	1.7	67	75	76
-423	Trans.	141 (18.6)	67.7		261	1.5		75	73
	Trans.	148 (18.6)	71.0		259	2.0		82	78
	Trans.	131 (18.6)	62.9		269	1.5		79	76
	Trans.	131 (18.6)	62.9		255	2.0		77	73
	Trans.	127 (18.6)	61.0		261	1.5		75	76
	Avg.	136	65.3	0.33	261	1.7	66	78	75

Table 6 (Cont'd.)

Test Temp. (°F)	Direction	Aged Weld T.S. (KSI)	Aged Weld Elongation (%)	Joint Efficiency (%)	Hardness - 15N Heat Affected Zone	Weld
75	Long.	215	1.0		87	87
	Long.	212	2.0		85	82
	Long.	224	1.5		88	86
	Long.	220	2.0		88	86
	Long.	233	1.0		88	87
	Avg.	221	1.5	78	87	86
75	Trans.	236	1.0		88	84
	Trans.	231	1.0		88	79
	Trans.	219	1.0		88	79
	Trans.	230	1.0		86	80
	Trans.	217	1.0		88	86
	Avg.	227	1.0	80	88	83
-100	Long.	278	1.0		88	84
	Long.	276	1.0		88	87
	Long.	280	1.0		88	85
	Long.	273	1.0		88	83
	Long.	266	1.0		87	82
	Avg.	275	1.0	90	88	84
-100	Trans.	280	1.5		87	85
	Trans.	273	1.0		88	85
	Trans.	277	1.0		88	83
	Trans.	258	1.0		87	84
	Trans.	274	1.0		87	81
	Avg.	272	1.1	87	87	84

Table 6 (Cont'd.)

Test Temp. (°F)	Direction	Aged Weld T.S. (KSI)	Aged Weld Elongation (%)	Joint Efficiency (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
-320	Long.	318	2.5		88	86
	Long.	307	2.0		87	84
	Long.	308	2.0		88	87
	Long.	315	1.5		86	85
	Long.	257	1.0		87	83
	Avg.	301	1.8	86	87	85
-320	Trans.	302	2.0		88	80
	Trans.	319	1.0		88	85
	Trans.	323	1.0		87	85
	Trans.	323	1.0		87	85
	Trans.	284	1.0		87	84
	Avg.	310	1.2	87	87	84
-423	Long.	296	1.0		87	84
	Long.	288	0.0		86	81
	Long.	284	0.0		81	82
	Long.	297	0.5		85	87
	Long.	297	0.5		87	87
	Avg.	292	0.4	73	85	84
-423	Trans.	262	0.5		87	86
	Trans.	330	0.5		88	85
	Trans.	308	0.5		86	85
	Trans.	324	0.0		87	81
	Trans.	301	0.4		88	85
	Avg.	305	0.4	76	87	84

Table 7.

MECHANICAL PROPERTIES OF HASTELLOY B (0.020 IN. SHEET, WALLINGFORD STEEL CO.)

Test Temp. (^oF)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness (15-N) Reduced Section	Hardness (15-N) Fractured Edge	Notched T. S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio
75	Long.	194	208	6.0	85.5	28.3	81	83	229(7.2)	64.1	
	Long.	192	208	6.0	91.9	29.6	82	83	226(7.2)	63.3	
	Long.	191	204	6.0	94.5	28.7	82	83	227(5.9)	63.6	
	Long.	190	204	5.5	93.1	28.5	82	83	228(7.2)	63.8	
	Long.	191	205	5.5	89.6	29.1	82	83	223(7.2)	62.4	
	Avg.	192	206	5.8	90.9	28.8	82	83	227	63.6	1.10
75	Trans.	168	200	5.5	71.9	29.0	82	83	218(5.8)	61.0	
	Trans.	170	202	7.0	89.7	29.7	82	83	218(5.8)	61.0	
	Trans.	163	193	8.5	72.7	30.1	81	83	219(5.8)	61.3	
	Trans.	169	202	7.5	78.5	30.4	82	84	221(5.8)	61.9	
	Trans.	168	202	8.0	72.3	29.8	82	83	212(5.8)	59.4	
	Avg.	168	200	7.3	77.0	29.8	82	83	218	61.0	1.09
-100	Long.	212	226	8.5	139	29.0	82	83	244(5.9)	68.3	
	Long.	210	231	10.0	156	29.5	82	83	245(7.2)	68.6	
	Long.	216	226	9.0	150	30.1	82	83	245(7.2)	68.6	
	Long.	205	223	8.5	149	29.7	82	84	246(5.9)	68.9	
	Long.	209	224	8.5	156	30.5	82	84	244(5.9)	68.3	
	Avg.	210	226	8.9	150	29.8	82	83	245	68.6	1.08
-100	Trans.	190	221	9.0	121	29.8	82	85	234(5.7)	65.5	
	Trans.	192	220	10.0	148	29.0	83	83	231(5.7)	64.7	
	Trans.	178	220	10.0	118	30.9	82	84	228(5.7)	63.8	
	Trans.	181	220	10.0	116	30.6	82	83	230(5.7)	64.4	
	Trans.	184	220	10.0	133	30.5	82	83	234(5.8)	65.5	
	Avg.	185	220	10.0	127	30.2	82	84	231	64.7	1.05

Table 7 (Cont'd.)

Test Temp. (°F)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness (15-N) Reduced Section	Hardness (15-N) Fractured Edge	Notched T. S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio
-320	Long.	237	259	14.0	169	29.9	83	83	265(5.9)	74.3	
	Long.	234	259	17.0	160	29.9	83	83	267(5.9)	74.8	
	Long.	237	258	18.0	189	29.8	82	84	264(7.2)	74.0	
	Long.	241	259	18.0	179	31.0	82	84	265(5.8)	74.3	
	Long.	236	257	18.0	184	29.8	81	84	265(5.7)	74.3	
	Avg.	237	258	17.0	176	30.1	82	84	265	74.3	1.03
-320	Trans.	207	249	17.0	137	30.5	82	83	253(5.8)	70.9	
	Trans.	213	259	18.0	147	31.0	82	84	250(5.8)	70.1	
	Trans.	197	239	22.0	136	29.5	82	85	246(5.8)	68.9	
	Trans.	193	241	21.5	130	29.7	82	84	241(5.8)	67.5	
	Trans.	209	251	17.0	120	29.7	82	84	249(5.8)	69.8	
	Avg.	204	248	19.1	134	30.1	82	84	248	69.5	1.00
-423	Long.	249	282	24.0	201	29.9	83	84	284(5.9)	79.5	
	Long.	248	282	-	176	31.0	83	84	289(5.7)	80.9	
	Long.	246	281	23.5	197	31.9	83	86	294(5.9)	82.3	
	Long.	258	284	25.5	-	30.8	82	83	286(6.4)	80.1	
	Long.	248	283	25.0	186	31.8	84	84	300(5.7)	84.0	
	Avg.	250	282	24.5	190	31.1	83	84	291	81.5	1.03
-423	Trans.	215	260	26.5	158	31.1	83	84	283(5.8)	79.2	
	Trans.	217	269	23.0	152	33.4	84	86	275(5.7)	77.0	
	Trans.	221	265	28.0	152	31.6	84	85	280(5.8)	78.4	
	Trans.	209	263	29.0	144	30.8	83	84	278(5.8)	77.8	
	Trans.	217	265	27.5	143	30.5	84	85	276(5.8)	77.3	
	Avg.	216	264	26.8	152	31.5	84	85	278	77.8	1.05

Table 7 (Cont'd.)

Test Temp. (°F)	Direction	Notched T.S. (K_t = 19) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Weld T. S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
75	Long.	187 (18.7)	89.8		136	2.5		76	76
	Long.	196 (18.7)	94.1		138	2.5		75	76
	Long.	199 (18.7)	95.5		130	2.5		75	73
	Long.	182 (18.7)	87.4		131	2.5		79	73
	Long.	195 (18.7)	93.6		134	2.5		75	76
	Avg.	192	92.2	0.93	134	2.5	65	76	75
75	Trans.	163 (18.8)	78.2		134	2.5		75	76
	Trans.	181 (18.8)	86.9		133	2.5		75	79
	Trans.	184 (18.8)	88.3		130	2.5		74	78
	Trans.	173 (18.8)	83.0		138	2.5		74	79
	Trans.	179 (18.8)	85.9		137	2.5		76	81
	Avg.	176	84.5	0.88	134	2.5	67	75	77
-100	Long.	222 (18.7)	107		149	1.5		76	76
	Long.	200 (18.7)	96.0		153	2.0		78	77
	Long.	194 (18.7)	93.1		150	1.5		77	76
	Long.	196 (18.7)	94.1		153	2.0		77	75
	Long.	204 (18.7)	97.9		151	1.5		77	75
	Avg.	203	97.4	0.90	151	1.7	67	77	76
-100	Trans.	175 (18.8)	84.0		156	2.0		77	80
	Trans.	175 (18.8)	84.0		155	2.0		75	78
	Trans.	185 (18.8)	88.8		156	2.0		77	78
	Trans.	183 (18.8)	87.8		153	2.0		75	77
	Trans.	187 (18.8)	89.8		156	2.0		74	80
	Avg.	181	86.9	0.82	155	2.0	70	76	79

Table 7 (Cont'd.)

Test Temp. (°F)	Direction	Notched T. S. (K_t = 19) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Weld T. S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
-320	Long.	239 (18.7)	115		180	2.0		77	78
	Long.	242 (18.7)	116		173	2.0		77	77
	Long.	235 (18.7)	113		181	2.0		76	76
	Long.	240 (18.7)	115		182	2.0		75	77
	Long.	241 (18.7)	116		179	2.0		75	78
	Avg.	239	115	0.93	179	2.0	69	76	77
-320	Trans.	219 (18.7)	105		178	2.0		76	79
	Trans.	221 (18.7)	106		178	2.0		75	79
	Trans.	213 (18.7)	102		179	2.0		75	74
	Trans.	217 (18.7)	104		178	2.0		76	78
	Trans.	215 (18.7)	103		178	2.0		75	78
	Avg.	217	104	0.83	178	2.0	72	75	78
-423	Long.	258 (18.7)	124		204	2.0		77	79
	Long.	244 (18.7)	117		198	2.0		76	78
	Long.	259 (18.7)	124		196	1.0		75	77
	Long.	244 (18.7)	117		198	2.5		77	75
	Long.	263 (18.7)	126		195	1.5		76	78
	Avg.	254	124	0.90	198	1.8	70	76	77
-423	Trans.	228 (18.7)	109		203	2.0		76	80
	Trans.	232 (18.7)	111		197	1.5		75	77
	Trans.	235 (18.7)	113		192	1.5		76	79
	Trans.	229 (18.7)	110		196	1.5		76	77
	Trans.	238 (18.7)	114		200	1.5		76	78
	Avg.	232	111	0.88	198	1.6	75	76	76

Table 8

MECHANICAL PROPERTIES OF TYPE 718 NICKEL ALLOY (0.025 IN. SHEET, HUNTINGTON DIVISION OF INTERNATIONAL NICKEL CO., HEAT NO. 6807EV)

Test Temp. (^oF)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness - 15N Reduced Section	Hardness - 15N Fractured Edge	Notched T. S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio
75	Long.	218	230	7.0	147	30.0	85	86	248 (6.1)	69.4	
	Long.	219	230	6.5	159	29.9	85	86	246 (6.1)	68.9	
	Long.	219	230	7.0	147	30.7	85	86	249 (6.1)	69.7	
	Long.	217	228	7.0	159	30.3	85	87	249 (6.1)	69.7	
	Long.	219	230	8.0	149	30.7	84	86	249 (6.1)	69.7	
	Avg.	218	230	7.1	152	30.3	85	86	248	69.4	1.08
75	Trans.	208	225	7.5	156	30.6	84	85	243 (5.7)	68.0	
	Trans.	207	225	7.5	146	30.1	85	86	249 (5.7)	69.7	
	Trans.	204	222	6.5	152	30.7	85	87	249 (5.7)	69.7	
	Trans.	205	222	7.0	158	30.0	85	86	250 (5.7)	70.0	
	Trans.	205	222	6.5	156	30.0	85	86	250 (5.8)	70.0	
	Avg.	206	223	7.0	154	30.3	85	86	248	69.4	1.11
-100	Long.	232	249	11.5	194	30.0	87	88	269 (6.1)	75.3	
	Long.	232	250	10.5	196	30.9	86	87	268 (6.1)	75.0	
	Long.	231	250	10.5	186	31.3	86	87	268 (6.1)	75.0	
	Long.	226	248	11.5	194	30.5	85	86	266 (6.3)	74.5	
	Long.	229	247	10.5	196	29.6	86	87	265 (6.1)	74.2	
	Avg.	230	249	10.9	193	30.5	86	87	267	74.8	1.07
-100	Trans.	218	242	8.5	181	29.9	86	88	262 (5.8)	73.4	
	Trans.	218	241	8.5	181	31.7	85	86	262 (5.8)	73.4	
	Trans.	223	242	8.5	185	30.8	86	87	263 (5.8)	73.6	
	Trans.	214	241	8.5	177	30.4	86	86	261 (5.8)	73.1	
	Trans.	218	243	8.0	179	29.3	85	86	261 (5.8)	73.1	
	Avg.	218	242	8.4	181	30.4	86	87	262	73.4	1.08

Table 8 (Cont'd.)

Test Temp. (°F)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness - 15N Reduced Section	Hardness - 15N Fractured Edge	Notched T. S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI /in.)	Notched/Unnotched Tensile Ratio
-320	Long.	258	291	17.5	220	31.8	86	87	296 (6.0)	82.9	
	Long.	260	293	15.0	223	31.9	85	87	285 (6.0)	79.8	
	Long.	258	293	15.0	215	32.7	86	87	289 (6.1)	80.9	
	Long.	258	289	15.0	216	32.2	86	87	291 (6.1)	81.5	
	Long.	261	293	16.0	224	31.3	86	87	299 (6.1)	83.7	
	Avg.	259	292	15.7	220	32.0	86	87	292	81.8	1.00
-320	Trans.	239	272	12.0	185	31.8	87	87	286 (5.8)	80.1	
	Trans.	234	268	11.5	183	31.4	85	86	285 (5.8)	79.8	
	Trans.	238	275	15.0	192	32.0	85	87	291 (5.8)	81.5	
	Trans.	239	275	15.0	199	31.8	85	87	283 (5.7)	79.2	
	Trans.	240	274	13.0	201	31.5	86	87	280 (5.7)	78.4	
	Avg.	238	273	13.3	192	31.7	86	87	285	79.8	1.04
-423	Long.	267	312	17.0	216	33.0	86	86	303 (6.1)	84.8	
	Long.	270	310	13.5	229	32.3	86	87	314 (6.1)	87.9	
	Long.	268	310	12.5	219	32.0	86	86	315 (6.1)	88.2	
	Long.	270	303	11.5	217	32.7	86	86	308 (6.0)	86.2	
	Long.	268	310	18.5	217	32.1	87	86	305 (6.1)	85.4	
	Avg.	269	309	14.6	220	32.4	86	86	309	86.5	1.00
-423	Trans.	253	294	15.5	193	32.8	87	87	307 (5.6)	86.0	
	Trans.	251	296	18.5	202	32.6	85	86	282 (5.6)	79.0	
	Trans.	255	297	18.0	215	32.4	85	86	301 (5.6)	84.3	
	Trans.	247	294	-	180	32.2	85	87	303 (5.6)	84.8	
	Trans.	249	295	12.0	196	32.9	86	87	310 (5.6)	86.8	
	Avg.	251	295	16.0	197	32.6	86	87	301	84.3	1.02

Table 8 (Cont'd.)

Test Temp (^{o}F)	Direction	Notched T.S. (K_t = 19) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Weld T. S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
75	Long.	210 (18.7)	101		109	1.5		81	72
	Long.	221 (18.7)	106		107	1.5		74	75
	Long.	212 (18.7)	102		119	3.0		78	77
	Long.	217 (18.7)	104		116	3.0		77	76
	Long.	213 (18.7)	102		112	2.5		75	75
	Avg.	215	103	0.93	113	2.1	49	77	75
75	Trans.	208 (18.8)	99.8		118	3.0		77	77
	Trans.	214 (18.8)	103		107	2.5		78	76
	Trans.	217 (18.8)	104		120	3.0		76	76
	Trans.	204 (18.8)	97.9		112	2.5		74	77
	Trans.	211 (18.8)	101		105	2.5		74	73
	Avg.	211	101	0.95	112	2.7	50	76	76
-100	Long.	209 (18.7)	100		138	1.0		76	74
	Long.	218 (18.7)	105		146	3.0		77	75
	Long.	202 (18.7)	97.0		148	3.0		76	77
	Long.	215 (18.7)	103		144	2.5		76	76
	Long.	212 (18.7)	102		146	2.5		75	77
	Avg.	211	101	0.85	144	3.0	58	76	76
-100	Trans.	200 (18.8)	96.0		120	1.5		72	73
	Trans.	189 (18.8)	90.7		126	1.5		75	77
	Trans.	197 (18.8)	94.6		133	1.0		77	71
	Trans.	201 (18.8)	96.5		143	2.5		74	77
	Trans.	200 (18.8)	96.0		129	1.5		72	72
	Avg.	197	94.6	0.81	130	1.6	54	74	74

Table 8 (Cont'd.)

Test Temp. (^{o}F)	Direction	Notched T. S. (K_t = 19) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Weld T. S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
-320	Long.	235 (18.7)	113		170	2.5		75	77
	Long.	224 (18.7)	108		175	2.5		76	79
	Long.	222 (18.7)	107		171	2.5		75	78
	Long.	241 (18.7)	116		168	1.0		78	78
	Long.	225 (18.7)	108		164	1.0		78	76
	Avg.	229	110	0.78	170	1.9	58	76	78
-320	Trans.	206 (18.7)	98.9		144	1.0		75	78
	Trans.	199 (18.7)	95.5		142	0.5		72	70
	Trans.	194 (18.7)	93.1		146	0.5		71	71
	Trans.	212 (18.7)	102		143	1.0		70	69
	Trans.	230 (18.8)	110		150	1.0		73	75
	Avg.	208	99.8	0.76	145	0.9	53	72	73
-423	Long.	257 (18.7)	123		162	0.5		72	71
	Long.	273 (18.7)	131		138	0.0		71	74
	Long.	261 (18.7)	125		159	1.0		73	72
	Long.	228 (18.7)	109		157	0.0		71	70
	Long.	242 (18.7)	116		152	0.5		71	71
	Avg.	252	121	0.82	154	0.6	50	72	72
-423	Trans.	239 (18.8)	115		148	1.0		71	72
	Trans.	246 (18.8)	118		147	1.0		71	71
	Trans.	250 (18.8)	120		139	1.0		73	77
	Trans.	223 (18.8)	107		149	0.5		73	71
	Trans.	247 (18.8)	119		145	1.0		72	73
	Avg.	241	116	0.82	146	0.9	50	72	73

Table 8 (Cont'd)

Test Temp. (^oF)	Direction	Aged Weld T.S. (KSI)	Aged Weld Elongation (%)	Joint Efficiency (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
75	Long.	193	1.5		83	76
	Long.	195	1.5		83	78
	Long.	190	1.5		86	82
	Long.	190	1.5		83	83
	Long.	194	2.0		83	80
	Avg.	192	1.6	84	84	80
75	Trans.	186	1.5		83	80
	Trans.	186	1.5		82	83
	Trans.	184	1.5		83	83
	Trans.	182	2.0		83	80
	Trans.	184	1.5		84	81
	Avg.	184	1.6	83	83	81
-100	Long.	208	1.5		83	79
	Long.	212	1.5		84	79
	Long.	210	1.5		84	86
	Long.	207	1.5		83	77
	Long.	200	1.5		83	81
	Avg.	207	1.5	83	83	80
-100	Trans.	202	1.5		82	79
	Trans.	199	1.5		84	81
	Trans.	197	1.5		83	82
	Trans.	204	1.5		83	82
	Trans.	203	1.5		83	80
	Avg.	201	1.5	83	81	81

Table 8 (Cont'd.)

Test Temp. (°F)	Direction	Aged Weld T. S. (KSI)	Aged Weld Elongation (%)	Joint Efficiency (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
-320	Long.	218	1.5		82	81
	Long.	237	2.5		83	79
	Long.	238	2.5		82	79
	Long.	236	1.0		83	81
	Long.	229	1.5		82	81
	Avg.	232	1.8	79	82	80
-320	Trans.	229	1.0		83	81
	Trans.	231	1.0		84	83
	Trans.	221	1.0		84	84
	Trans.	230	2.0		83	82
	Trans.	228	1.0		84	81
	Avg.	228	1.2	84	84	82
-423	Long.	258	1.0		85	83
	Long.	265	1.0		84	81
	Long.	254	1.5		82	82
	Long.	259	1.5		84	83
	Long.	256	1.0		84	84
	Avg.	258	1.2	84	84	83
-423	Trans.	252	1.0		84	79
	Trans.	247	1.0		84	82
	Trans.	248	1.0		83	82
	Trans.	245	1.0		84	83
	Trans.	252	1.0		85	83
	Avg.	249	1.0	84	84	82

Table 9

MECHANICAL PROPERTIES OF 7039-T6 ALUMINUM ALLOY
(0.063 IN. SHEET, KAISER ALUMINUM CO.)

Test Temp. (^oF)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness - 15N Reduced Section	Hardness - 15N Fractured Edge	Notched T. S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio
75	Long.	62.9	68.8	10.5	54.5	9.8	60	60	74.5(6.3)	20.9	
	Long.	62.4	68.8	11.0	55.6	9.6	60	60	74.6(6.5)	20.9	
	Long.	63.0	69.1	11.0	56.2	9.8	60	60	74.0(6.5)	20.7	
	Long.	62.8	69.3	10.5	54.0	9.9	59	60	74.7(6.5)	20.9	
	Long.	62.6	68.8	11.0	56.0	9.8	59	59	74.1(6.5)	20.7	
	Avg.	62.7	**69.0**	10.8	55.3	9.8	60	60	74.4	20.8	1.08
75	Trans.	59.6	68.4	10.0	48.9	10.4	60	60	72.4(6.3)	20.3	
	Trans.	59.9	68.3	10.5	48.7	9.8	60	59	71.9(6.3)	20.1	
	Trans.	59.9	68.2	11.0	48.2	10.3	59	60	72.0(6.3)	20.2	
	Trans.	59.7	68.2	10.5	52.9	10.3	60	60	71.7(6.3)	20.0	
	Trans.	59.9	68.2	11.0	48.1	9.8	60	59	72.1(6.4)	20.2	
	Avg.	59.8	68.3	10.6	49.4	10.1	60	60	72.0	20.2	1.05
-100	Long.	66.8	74.1	12.5	54.5	10.7	60	60	77.1(6.5)	21.6	
	Long.	67.1	74.2	13.5	58.8	10.6	61	61	77.8(6.5)	21.8	
	Long.	66.6	74.2	12.5	59.6	10.2	60	60	77.4(6.5)	21.7	
	Long.	66.5	74.0	11.0	58.6	9.9	60	61	77.1(6.5)	21.6	
	Long.	66.7	74.3	13.0	59.4	9.8	60	59	78.0(6.5)	21.8	
	Avg.	66.7	74.2	12.5	58.2	10.2	60	60	77.5	21.7	1.04
-100	Trans.	64.2	73.7	12.0	53.4	9.6	59	60	77.0(6.3)	21.6	
	Trans.	64.2	73.7	12.5	49.4	10.0	60	59	76.6(6.5)	21.4	
	Trans.	64.5	73.9	12.0	53.9	10.3	61	59	75.6(6.3)	21.2	
	Trans.	65.3	74.0	11.5	53.1	10.0	60	59	76.9(6.3)	21.5	
	Trans.	64.7	73.9	12.0	51.4	9.9	60	59	75.5(6.3)	21.1	
	Avg.	64.6	73.8	12.0	52.2	10.0	60	59	76.3	21.4	1.03

Table 9 (Cont'd.)

Test Temp. (^{o}F)	Direction	F_{ty} (KSI)	F_{tu} (KSI)	Elongation (%)	Proportional Limit (KSI)	Elastic Modulus (PSI x 10^6)	Hardness - 15N Reduced Section	Hardness - 15N Fractured Edge	Notched T. S. (K_t=6.3) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio
-320	Long.	72.6	85.8	16.0	64.5	11.0	61	60	80.3(6.3)	22.5	
	Long.	74.6	86.1	15.0	61.9	11.3	60	60	81.5(6.3)	22.8	
	Long.	75.1	86.1	15.0	61.3	11.6	59	60	83.4(6.3)	23.4	
	Long.	74.7	85.8	14.5	62.0	11.6	60	61	83.4(6.3)	23.4	
	Long.	75.2	86.1	15.0	-	11.4	61	60	82.7(6.3)	23.2	
	Avg.	74.4	86.0	15.1	62.4	11.4	60	60	82.3	23.0	0.96
-320	Trans.	72.3	85.7	14.0	64.4	10.9	59	61	76.1(6.3)	21.3	
	Trans.	70.8	85.6	13.5	55.5	10.7	60	60	80.0(6.5)	22.4	
	Trans.	71.0	85.6	14.5	59.0	10.3	60	60	79.7(6.5)	22.3	
	Trans.	70.7	85.3	14.5	55.0	10.1	60	60	81.6(6.5)	22.8	
	Trans.	71.4	85.6	15.0	57.0	10.9	61	60	74.8(6.3)	20.9	
	Avg.	71.2	85.6	14.3	58.2	10.6	60	60	78.4	22.0	0.92
-423	Long.	78.1	99.3	13.5	64.8	11.1	60	60	75.1(6.3)	21.0	
	Long.	79.6	99.6	14.5	73.2	10.9	60	61	83.0(6.3)	23.2	
	Long.	77.7	99.4	14.0	65.1	11.9	61	61	81.7(6.3)	22.9	
	Long.	78.8	99.3	14.0	70.1	11.0	61	60	85.3(6.3)	23.9	
	Long.	78.5	99.0	14.0	68.8	11.3	61	60	87.6(6.3)	24.5	
	Avg.	78.5	99.3	14.0	68.4	11.2	61	60	82.5	23.1	0.83
-423	Trans.	76.2	98.2	13.0	65.8	11.1	60	59	82.5(6.5)	23.1	
	Trans.	76.1	97.8	11.5	63.0	11.0	60	59	81.8(6.5)	22.9	
	Trans.	76.3	96.9	10.5	65.9	11.4	60	60	86.6(6.5)	24.2	
	Trans.	76.1	98.7	13.5	61.5	11.0	60	60	79.6(6.5)	22.3	
	Trans.	75.0	96.6	9.0	62.8	10.6	60	60	82.3(6.5)	23.0	
	Avg.	75.9	97.6	11.5	63.8	11.0	60	60	82.6	23.1	0.85

Table 9 (Cont'd.)

Test Temp. (^oF)	Direction	Notched T.S. (K_t = 19) (KSI)	Fracture Toughness $K(KSI\sqrt{in.})$	Notched/ Unnotched Tensile Ratio	Weld T. S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15N Heat Affected Zone	Hardness - 15N Weld
75	Long.	67.8 (18.8)	32.5		55.8	9.0		50	30
	Long.	68.1 (18.8)	32.7		56.8	10.0		52	35
	Long.	67.6 (18.8)	32.4		55.0	9.0		51	31
	Long.	68.6 (18.8)	32.9		53.9	10.0		49	36
	Long.	68.2 (18.8)	32.7		55.9	7.5		53	29
	Avg.	68.6	32.6	1.0	55.5	9.1	81	51	32
75	Trans.	64.9 (18.8)	31.2		54.9	10.0		55	32
	Trans.	65.3 (18.8)	31.3		55.1	9.0		55	30
	Trans.	65.6 (18.8)	31.5		55.3	8.0		55	37
	Trans.	65.5 (18.8)	31.4		54.4	10.0		56	31
	Trans.	64.0 (18.8)	30.7		54.8	10.0		53	34
	Avg.	65.1	31.2	0.95	54.9	9.4	80	55	33
-100	Long.	62.7 (18.8)	30.1		55.6	10.0		54	43
	Long.	61.4 (18.8)	29.5		58.2	13.0		52	40
	Long.	66.0 (18.8)	31.7		55.8	9.0		51	35
	Long.	68.7 (18.8)	30.5		54.8	6.0		54	39
	Long.	63.5 (18.8)	30.5		57.1	4.0		54	46
	Avg.	64.5	31.0	0.87	56.3	8.4	76	53	41
-100	Trans.	62.1 (18.8)	29.8		55.5	8.0		54	29
	Trans.	61.6 (18.8)	29.6		57.3	11.0		56	32
	Trans.	60.3 (18.8)	28.9		58.1	10.0		55	32
	Trans.	57.2 (18.8)	27.5		56.1	11.0		57	38
	Trans.	57.9 (18.8)	27.8		53.8	7.0		55	29
	Avg.	59.8	28.7	0.81	56.2	9.4	76	55	32

Table 9 (Cont'd.)

Test Temp. (^oF)	Direction	Notched T.S. (K_t = 19) (KSI)	Fracture Toughness K(KSI $\sqrt{in.}$)	Notched/ Unnotched Tensile Ratio	Weld T. S. (KSI)	Weld Elong. (%)	Joint Eff. (%)	Hardness - 15 N Heat Affected Zone	Hardness - 15 N Weld
-320	Long.	53.0 (18.8)	25.4		60.5	-		54	33
	Long.	48.3 (18.8)	23.2		53.9	6.0		51	39
	Long.	49.1 (18.8)	23.6		64.7	8.0		52	35
	Long.	48.3 (18.8)	23.2		52.4	6.0		52	39
	Long.	52.1 (18.8)	25.0		62.4	9.0		52	42
	Avg.	50.2	24.1	0.58	58.8	7.2	68	52	38
-320	Trans.	42.0 (18.8)	20.2		56.6	7.0		53	47
	Trans.	41.7 (18.8)	20.0		57.4	7.0		52	39
	Trans.	46.0 (18.8)	22.1		58.2	6.0		52	39
	Trans.	47.2 (18.8)	22.7		61.1	6.0		52	40
	Trans.	42.9 (18.8)	20.6		59.5	7.0		51	42
	Avg.	44.0	21.1	0.51	58.6	6.6	68	52	41
-423	Long.	56.8 (18.8)	27.3		43.9	1.0		46	37
	Long.	61.4 (18.8)	29.5		54.7	0.5		50	43
	Long.	59.1 (18.8)	28.4		50.6	1.0		46	35
	Long.	53.6 (18.8)	25.7		51.8	0.5		47	43
	Long.	55.8 (18.8)	26.8		56.0	1.5		51	43
	Avg.	57.3	27.5	0.58	51.4	0.9	52	48	40
-423	Trans.	45.5 (18.8)	21.8		56.5	0.5		46	37
	Trans.	49.5 (18.8)	23.8		55.3	1.0		48	36
	Trans.	48.7 (18.8)	23.4		55.8	0.5		49	39
	Trans.	46.1 (18.8)	22.1		58.9	0.5		48	37
	Trans.	49.4 (18.8)	23.7		57.8	1.0		49	39
	Avg.	47.8	22.9	0.49	56.9	0.7	58	48	38

Table 10.

PROPERTIES OF RESISTANCE SPOT WELDS OF 70 PERCENT COLD ROLLED TYPE 304 STAINLESS STEEL (0.020 IN. SHEET, ALLEGHENY-LUDLUM STEEL CORP., HEAT NO. 94997)

Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
75	295	643		-100	412	995	
	287	654			420	976	
	262	667			398	1010	
	294	655			362	1025	
	302	646			434	1010	
	326	755			416	963	
	350	748			373	940	
	369	757			401	1000	
	307	749			329	922	
	326	730			362	978	
	350	684			354	963	
	406	712			412	981	
	392	729			378	866	
	306	673			362	914	
	350	689			419	982	
	392	742			374	1020	
	369	731			372	1010	
	307	671			391	994	
	291	704			416	892	
	312	673			344	926	
Avg.	330	761	0.47		386	968	0.40

Table 10 (Cont.)

Test Temp. (^{o}F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (^{o}F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
-320	374	1250		-423	275	1185	
	356	1140			272	1090	
	323	1075			256	1200	
	337	1240			289	1055	
	331	1225			273	1040	
	373	1150			312	1140	
	412	1125			264	1210	
	419	1165			380	1165	
	401	1210			263	1080	
	382	1045			284	1095	
	423	1090			304	1080	
	417	1205			287	1115	
	366	1170			263	1220	
	394	1120			274	1200	
	412	1145			344	1180	
	440	1210			293	1085	
	419	1075			276	1125	
	386	1190			372	1145	
	404	1105			258	1140	
	397	1215			307	1205	
Avg.	388	1157	0.34		292	1138	0.26

Table 11.

PROPERTIES OF RESISTANCE SPOT WELDS OF 18 PERCENT NICKEL MARAGING STEEL
(0.025 IN. SHEET, LATROBE STEEL CO., HEAT NO. C56858)

Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
75	509	942		-100	499	958	
	468	881			528	1160	
	455	1018			480	1213	
	410	878			473	1172	
	478	1116			521	1027	
	524	858			459	1204	
	490	1019			481	1219	
	432	1058			503	1257	
	512	1158			500	1062	
	466	862			522	1248	
	426	940			561	1513	
	468	1090			460	999	
	484	1040			478	1261	
	444	1046			522	1218	
	497	838			490	965	
	486	915			452	1238	
	453	1068			472	1175	
	509	1023			483	1210	
	447	836			482	1030	
	440	1064			518	1253	
Avg.	470	983	0.48		494	1169	0.42

Table 11 (Cont.)

Test Temp. (^oF)	Cross-Tension Strength (lbs./spot)	Tensile Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (^oF)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
-320	596	1365		-423	407	1402	
	570	1665			400	1605	
	532	1760			408	1615	
	562	1625			475	1570	
	468	1525			485	1935	
	521	2055			408	2000	
	529	1300			453	1187	
	594	1310			550	1640	
	627	1600			430	1560	
	581	1735			468	1590	
	521	1300			433	1320	
	583	1395			430	1605	
	594	1625			447	1660	
	527	1580			398	1700	
	513	1510			467	1690	
	638	1640			438	1575	
	484	1780			458	1620	
	528	1720			516	1452	
	505	1905			384	1700	
	568	1355			480	1677	
Avg.	552	1588	0.35		447	1605	0.28

Table 12

PROPERTIES OF RESISTANCE SPOT WELDS OF HASTELLOY B
(0.020 IN. SHEET, WALLINGFORD STEEL CO.)

Test Temp. (^oF)	Cross-Tension Strength (lbs./spot)	Tensile Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (^oF)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
75	355	945		-100	276	971	
	292	992			328	940	
	254	923			275	1000	
	274	911			292	982	
	232	962			282	944	
	299	929			279	1020	
	272	896			260	1030	
	249	955			316	1025	
	318	921			286	998	
	252	963			354	996	
	263	1010			326	964	
	322	925			272	1020	
	275	958			259	996	
	250	930			268	964	
	326	925			281	1045	
	298	927			306	1010	
	262	963			285	1045	
	282	918			242	1065	
	274	952			284	1025	
	328	945			304	1045	
Avg.	284	943	0.30	28	289	1004	0.29

Table 12 (Cont.)

Test Temp (^oF)	Cross-Tension Strength (lbs./spot)	Tensile Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (^oF)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
-320	319	1106		-423	350	1058	
	338	1121			328	1133	
	297	1100			297	1158	
	373	1083			340	1194	
	326	1070			279	1163	
	281	1115			343	1152	
	309	1104			375	1148	
	308	1082			317	1169	
	308	1075			340	1177	
	347	1119			343	1151	
	305	1075			279	1162	
	301	1050			332	1021	
	300	1130			334	1089	
	329	1075			289	1092	
	311	1070			340	1200	
	343	1110			327	948	
	284	1102			310	1049	
	302	1092			336	1200	
	273	1066			308	1167	
	278	1092			364	1156	
Avg.	312	1092	0.29		327	1129	0.29

Table 13.

PROPERTIES OF RESISTANCE SPOT WELDS OF TYPE 718 NICKEL ALLOY (0.025 IN. SHEET, HUNTINGTON DIVISION OF INTERNATIONAL NICKEL CO., HEAT NO. 6807EV)

Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
75	459	670		-100	450	765	
	404	626			466	682	
	464	658			480	736	
	452	733			462	744	
	407	721			470	742	
	417	678			452	686	
	423	755			525	784	
	482	700			414	760	
	456	722			438	724	
	477	645			422	636	
	466	653			446	690	
	412	702			416	716	
	454	683			466	710	
	408	593			362	770	
	458	776			432	752	
	454	721			442	738	
	467	732			446	736	
	415	629			490	704	
	477	676			462	712	
	467	709			470	730	
Avg.	446	689	0.65		451	726	0.62

Table 13 (Cont.)

Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
-320	410	697		-423	377	814	
	482	781			372	954	
	470	819			468	930	
	430	862			436	879	
	434	828			429	868	
	436	798			443	804	
	458	781			430	860	
	468	866			392	917	
	454	805			405	795	
	452	776			430	782	
	480	874			480	935	
	482	865			338	895	
	470	817			413	896	
	470	790			452	932	
	476	769			413	837	
	414	741			448	888	
	432	844			466	911	
	430	856			458	[illegible]	
	512	815			438	896	
	476	757			362	853	
Avg.	457	807	0.57		423	882	0.48

Table 14

PROPERTIES OF RESISTANCE SPOT WELDS OF 7039-T6 ALUMINUM ALLOY
(0.063 IN. SHEET, KAISER ALUMINUM CO.)

Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (°F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
75	528	1145		-100	432	1248	
	512	1221			428	1235	
	506	1185			499	1206	
	447	1177			475	1359	
	490	1250			482	1246	
	442	1160			419	1272	
	477	1140			446	1321	
	424	1253			460	1321	
	521	1112			482	1362	
	506	1313			476	1330	
	538	1277			452	1355	
	450	1245			472	1182	
	489	1239			481	1300	
	483	1233			486	1298	
	503	1241			467	1297	
	535	1100			418	1253	
	505	1130			433	1272	
	470	1217			457	1300	
	503	1312			460	1241	
	475	1298			444	1260	
Avg.	490	1212	0.40		458	1283	0.36

Table 14 (Cont'd.)

Test Temp. (^{o}F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio	Test Temp. (^{o}F)	Cross-Tension Strength (lbs./spot)	Tensile-Shear Strength (lbs./spot)	Tension/Shear Ratio
-320	290	1066		-423	245	983	
	320	1125			250	1018	
	309	1142			234	1015	
	302	1080			221	1050	
	301	1163			238	969	
	286	1059			269	1000	
	268	1081			221	1044	
	293	1066			218	997	
	303	1077			198	1005	
	289	1075			253	1024	
	278	1023			257	1103	
	217	1103			266	1072	
	280	1042			222	1035	
	285	1107			261	969	
	321	1035			233	991	
	290	1021			247	1139	
	311	1168			249	1111	
	269	1062			247	996	
	308	1105			242	1087	
	316	1078			207	1110	
Avg.	292	1084	0.27		239	1036	0.23

Table 15.

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF 18 PERCENT NICKEL MARAGING STEEL

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	75	7L1	-	-	-	259	Failed First Row Spot Welds
Long.	75	7L2	-	-	-	256	Failed First Row Spot Welds
Long.	75	7L7	0-245	-	-	245	Failed Statically
Long.	75	7L8	0-245	-	61		Failed First Row Spot Welds
Long.	75	7L9	0-245	-	39		Failed First Row Spot Welds
Long.	75	7L10	0-245	-	-	242	Failed Statically
Avg.				-	50	251	
Long.	75	7L11	0-219	-	76		Failed First Row Spot Welds
Long.	75	7L12	0-219	100	156		Failed First Row Spot Welds
Long.	75	7L13	0-219	100	111		Failed First Row Spot Welds
Long.	75	7L14	0-219	100	165		Failed First Row Spot Welds
Avg.				100	127		
Long.	75	7L15	0-194	300	363		Failed First Row Spot Welds
Long.	75	7L16	0-194	300	339		Failed First Row Spot Welds
Long.	75	7L17	0-194	350	401		Failed First Row Spot Welds
Long.	75	7L18	0-194	300	349		Failed First Row Spot Welds
Avg.				313	363		
Tran.	75	7T1	-	-	-	252	Failed First Row Spot Welds
Tran.	75	7T2	-	-	-	259	Failed First Row Spot Welds
Tran.	75	7T7	0-219	100	118		Failed First Row Spot Welds
Tran.	75	7T8	0-219	100	102		Failed First Row Spot Welds
Tran.	75	7T9	0-219	150	178		Failed First Row Spot Welds
Avg.				117	133	256	

Table 15 (Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF 18 PERCENT NICKEL MARAGING STEEL

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-320	7L3	-	-	-	333	Failed First Row Spot Welds
Long.	-320	7L4	-	-	-	337	Failed Each Side of Doubler
Long.	-320	7L19	0-318	-	29		Failed First Row Spot Welds
Long.	-320	7L20	0-318	-	21		Failed First Row Spot Welds
Long.	-320	7L21	0-318	-	6		Failed First Row Spot Welds
Long.	-320	7L22	0-318	-	37		Failed First Row Spot Welds
Avg.				-	23	335	
Long.	-320	7L23	0-285	-	98		Failed First Row Spot Welds
Long.	-320	7L24	0-285	-	81		Failed First Row Spot Welds
Long.	-320	7L25	0-285	-	137		Failed First Row Spot Welds
Long.	-320	7L26	0-285	-	113		Failed First Row Spot Welds
Avg.				-	107		
Long.	-320	7L27	0-251	-	231		Failed First Row Spot Welds
Long.	-320	7L28	0-251	-	281		Failed First Row Spot Welds
Long.	-320	7L29	0-251	-	285		Failed First Row Spot Welds
Long.	-320	7L30	0-251	-	291		Failed First Row Spot Welds
Avg.				-	272		
Tran.	-320	7T3	-	-	-	333	Failed Each Side of Doubler
Tran.	-320	7T4	-	-	-	335	Failed First Row Spot Welds
Tran.	-320	7T10	0-285	-	53		Failed First Row Spot Welds
Tran.	-320	7T11	0-285	-	80		Failed First Row Spot Welds
Tran.	-320	7T12	0-285	-	80		Failed First Row Spot Welds
Avg.				-	71	334	

Table 15 (Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF 18 PERCENT NICKEL MARAGING STEEL

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-423	7L5	-	-	-	335	Failed First Row Spot Welds
Long.	-423	7L6	-	-	-	292	Failed First Row Spot Welds
Long.	-423	7L31	0-298	50	53		Failed First Row Spot Welds
Long.	-423	7L32	0-298	-	62		Failed First Row Spot Welds
Long.	-423	7L33	0-298	-	-	291	Failed Statically
Long.	-423	7L34	0-298	-	18		Failed First Row Spot Welds
Avg.				50	44	306	
Long.	-423	7L35	0-266				
Long.	-423	7L36	0-266				
Long.	-423	7L37	0-266				
Long.	-423	7L38	0-266				
Avg.							
Long.	-423	7L39	0-235				
Long.	-423	7L40	0-235				
Long.	-423	7L41	0-235				
Long.	-423	7L42	0-235				
Avg.							
Tran.	-423	7T5	0-237	-	-	277	Failed First Row Spot Welds
Tran.	-423	7T6	0-237	-	-	281	Failed First Row Spot Welds
Tran.	-423	7T13	0-237				
Tran.	-423	7T14	0-237				
Tran.	-423	7T15	0-237				
Avg.				-	-	279	

Table 16.

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF HASTELLOY B

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	75	9L1	-	-	-	211	Failed First Row Spot Welds
Long.	75	9L2	-	-	-	211	Failed First Row Spot Welds
Long.	75	9L7	0-200				
Long.	75	9L8	0-200				
Long.	75	9L9	0-200				
Long.	75	9L10	0-200				
Avg.				-	-	211	
Long.	75	9L11	0-180				
Long.	75	9L12	0-180				
Long.	75	9L13	0-180				
Long.	75	9L14	0-180				
Avg.							
Long.	75	9L15	0-158				
Long.	75	9L16	0-158				
Long.	75	9L17	0-158				
Long.	75	9L18	0-158				
Avg.							
Tran.	75	9T1	-	-	-	208	Failed First Row Spot Welds
Tran.	75	9T2	-	-	-	205	Failed Center Lap Weld
Tran.	75	9T7	0-175				
Tran.	75	9T8	0-175				
Tran.	75	9T9	0-175				
Avg.				-	-	207	

Table 16 (Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF HASTELLOY B

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-320	9L3	-	-	-	251	Failed First Row Spot Welds
Long.	-320	9L4	-	-	-	255	Failed First Row Spot Welds
Long.	-320	9L19	0-240				
Long.	-320	9L20	0-240				
Long.	-320	9L21	0-240				
Long.	-320	9L22	0-240				
Avg.				-	-	253	
Long.	-320	9L23	0-215				
Long.	-320	9L24	0-215				
Long.	-320	9L25	0-215				
Long.	-320	9L26	0-215				
Avg.							
Long.	-320	9L27	0-189				
Long.	-320	9L28	0-189				
Long.	-320	9L29	0-189				
Long.	-320	9L30	0-189				
Avg.							
Tran.	-320	9T3	-	-	-	239	Failed Center Lap Weld
Tran.	-320	9T4	-	-	-	236	Failed First Row Spot Welds
Tran.	-320	9T10	0-202				
Tran.	-320	9T11	0-202				
Tran.	-320	9T12	0-202				
Avg.				-	-	238	

Table 16 (Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF HASTELLOY B

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-423	9L5	-	-	-	266	Failed First Row Spot Welds
Long.	-423	9L6	-	-	-	276	Failed First Row Spot Welds
Long.	-423	9L31	0-257				
Long.	-423	9L32	0-257				
Long.	-423	9L33	0-257				
Long.	-423	9L34	0-257				
Avg.				-	-	271	
Long.	-423	9L35	0-230				
Long.	-423	9L36	0-230				
Long.	-423	9L37	0-230				
Long.	-423	9L38	0-230				
Avg.							
Long.	-423	9L39	0-203				
Long.	-423	9L40	0-203				
Long.	-423	9L41	0-203				
Long.	-423	9L42	0-203				
Avg.							
Tran.	-423	9T5	-	-	-	260	Failed First Row Spot Welds
Tran.	-423	9T6	-	-	-	251	Failed First Row Spot Welds
Tran.	-423	9T13	0-218				
Tran.	-423	9T14	0-218				
Tran.	-423	9T15	0-218				
Avg.				-	-	256	

Table 17

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF TYPE 718 NICKEL ALLOY

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	75	8L1	-	-	-	211	Failed First Row Spot Welds
Long.	75	8L2	-	-	-	222	Failed First Row Spot Welds
Long.	75	8L7	0-205				
Long.	75	8L8	0-205				
Long.	75	8L9	0-205				
Long.	75	8L10	0-205				
Avg.						217	
Long.	75	8L11	0-184				
Long.	75	8L12	0-184				
Long.	75	8L13	0-184				
Long.	75	8L14	0-184				
Avg.							
Long.	75	8L15	0-162				
Long.	75	8L16	0-162				
Long.	75	8L17	0-162				
Long.	75	8L18	0-162				
Avg.							
Tran.	75	8T1	-	-	-	173	Failed Center Lap Weld
Tran.	75	8T2	-	-	-	193	Failed Center Lap Weld
Tran.	75	8T7	0-155				
Tran.	75	8T8	0-155				
Tran.	75	8T9	0-155				
Avg.						183	

Table 17.(Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF TYPE 718 NICKEL ALLOY

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-320	8L3	-	-	-	266	Failed First Row Spot Welds
Long.	-320	8L4	-	-	-	241	Failed First Row Spot Welds
Long.	-320	8L19	0-240	-	78		Failed First Row Spot Welds
Long.	-320	8L20	0-240	-	105		Failed First Row Spot Welds
Long.	-320	8L21	0-240	-	76		Failed First Row Spot Welds
Long.	-320	8L22	0-240	-	59		Failed First Row Spot Welds
Avg.				-	80	254	
Long.	-320	8L23	0-216	-	192		Failed First Row Spot Welds
Long.	-320	8L24	0-216	-	252		Failed First Row Spot Welds
Long.	-320	8L25	0-216	-	248		Failed First Row Spot Welds
Long.	-320	8L26	0-216	-	99		Failed First Row Spot Welds
Avg.				-	198		
Long.	-320	8L27	0-190	600	614		Failed First Row Spot Welds
Long.	-320	8L28	0-190	-	617		Failed First Row Spot Welds
Long.	-320	8L29	0-190	-	632		Failed First Row Spot Welds
Long.	-320	8L30	0-190	-	637		Failed First Row Spot Welds
Avg.				600	625		
Tran.	-320	8T3	-	-	-	211	Failed At Buttweld of Lap
Tran.	-320	8T4	-	-	-	197	Failed At Buttweld of Lap
Tran.	-320	8T10	0-173				
Tran.	-320	8T11	0-173				
Tran.	-320	8T12	0-173				
Avg.				-	-	204	

Table 17 (Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF TYPE 718 NICKEL ALLOY

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-423	8L5	-	-	-	285	Failed First Row Spot Welds
Long.	-423	8L6	-	-	-	258	Failed First Row Spot Welds
Long.	-423	8L31	0-258				
Long.	-423	8L32	0-258				
Long.	-423	8L33	0-258				
Long.	-423	8L34	0-258				
Avg.				-	-	272	
Long.	-423	8L35	0-231				
Long.	-423	8L36	0-231				
Long.	-423	8L37	0-231				
Long.	-423	8L38	0-231				
Avg.							
Long.	-423	8L39	0-204				
Long.	-423	8L40	0-204				
Long.	-423	8L41	0-204				
Long.	-423	8L42	0-204				
Avg.							
Tran.	-423	8T5	-	-	-	208	Failed Center Lapweld
Tran.	-423	8T6	-	-	-	210	Failed Center Lapweld
Tran.	-423	8T13	0-178				
Tran.	-423	8T14	0-178				
Tran.	-423	8T15	0-178				
Avg.				-	-	209	

Table 18

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF 7039-T6 ALUMINUM ALLOY

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	75	5L1	-	-	59.4	Failed in Heat Affected Zone
Long.	75	5L2	-	-	52.1	Failed in Heat Affected Zone
Long.	75	5L7	0-53.0	785		Failed at Edge Butt Weld
Long.	75	5L8	0-53.0	404		Failed at Edge Butt Weld
Long.	75	5L9	0-53.0	467		Failed at Edge Butt Weld
Long.	75	5L10	0-53.0	354		Failed at Edge Butt Weld
Avg.				500	55.8	
Long.	75	5L11	0-47.4	1021		Failed at Edge Butt Weld
Long.	75	5L12	0-47.4	946		Failed at Edge Butt Weld
Long.	75	5L13	0-47.4	1054		Failed at Edge Butt Weld
Long.	75	5L14	0-47.4	798		Failed at Edge Butt Weld
Avg.				955		
Long.	75	5L15	0-41.8	1863		Failed at Butt Weld
Long.	75	5L16	0-41.8	2000+		No Failure
Long.	75	5L17	0-41.8	2000+		No Failure
Long.	75	5L18	0-41.8	1373		Failed at Butt Weld
Avg.				1809+		
Tran.		5T1			52.4	Failed at Edge of Buttweld
Tran.		5T2			57.5	Failed Half in Weld Half in Heat Affected Zone.
Tran.		5T7	0-47.4	594		Failed at Butt Weld
Tran.		5T8	0-47.4	645		Failed at Butt Weld
Tran.		5T9	0-47.4	617		Failed at Butt Weld
Avg.				464	55.0	

Table 18 (Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF 7039-T6 ALUMINUM ALLOY

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-320	5L3	-	-	61.1	Failed at Edge of Buttweld
Long.	-320	5L4	-	-	63.8	Failed at Edge of Buttweld
Long.	-320	5L19	0-59.4	-	56.3	Failed Statically
Long.	-320	5L20	0-59.4	-	56.2	Failed Statically
Long.	-320	5L21	0-59.4	-	48.8	Failed Statically
Long.	-320	5L22	0-59.4	-	57.8	Failed Statically
Avg.				-	57.3	
Long.	-320	5L23	0-53.1	2000+		No Failure
Long.	-320	5L24	0-53.1	-	52.7	Failed Statically
Long.	-320	5L25	0-53.1	2000+		No Failure
Long.	-320	5L26	0-53.1	-	52.8	Failed Statically
Avg.					52.8	
Long.	-320	5L27	0-46.9	2000+		No Failure
Long.	-320	5L28	0-46.9	2000+		No Failure
Long.	-320	5L29	0-46.9	2000+		No Failure
Long.	-320	5L30	0-46.9	2000+		No Failure
Avg.				2000+		
Tran.	-320	5T3			56.1	Failed at Edge of Buttweld
Tran.	-320	5T4			53.1	Failed at Edge of Buttweld
Tran.	-320	5T10	0-46.4	2000+		No Failure
Tran.	-320	5T11	0-46.4	2000+		No Failure
Tran.	-320	5T12	0-46.4	2000+		No Failure
Avg.				2000+	54.6	

Table 18 (Cont.)

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF 7039-T6 ALUMINUM ALLOY

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Long.	-423	5L5	-	-	52.0	Failed at Buttweld
Long.	-423	5L6	-	-	61.3	Failed at Buttweld
Long.	-423	5L31	0-53.8	449		Failed at Edge Buttweld
Long.	-423	5L32	0-53.8	2000+		No Failure
Long.	-423	5L33	0-53.8	6		Failed at Edge Buttweld
Long.	-423	5L34	0-53.8	780		Failed at Edge Buttweld
Avg.				809+	56.7	
Long.	-423	5L35	0-48.1	1356		Failed at Edge Buttweld
Long.	-423	5L36	0-48.1	2000+		No Failure
Long.	-423	3L37	0-48.1	2000+		No Failure
Long.	-423	3L38	0-48.1	2000+		No Failure
Avg.				1839+		
Long.	-423	5L39	0-42.5	2000+		No Failure
Long.	-423	5L40	0-42.5	2000+		No Failure
Long.	-423	5L41	0-42.5	2000+		No Failure
Long.	-423	5L42	0-42.5	2000+		No Failure
Avg.				2000+		
Tran.	-423	5T5	-	-	54.1	Failed at Buttweld
Tran.	-423	5T6	-	-	52.7	Failed at Buttweld
Tran.	-423	5T13	0-45.3			
Tran.	-423	5T14	0-45.3			
Tran.	-423	5T15	0-45.3			
Avg.				-	53.4	

Table 19.

FATIGUE PROPERTIES OF COMPLEX WELDED JOINTS OF RENE 41 ALLOY

DIR.	TEST TEMP (°F)	SPECIMEN NO.	STRESS RANGE (KSI)	NO. OF CYCLES TO FIRST LEAK	NO. OF CYCLES TO FAILURE	STATIC STRENGTH (KSI)	REMARKS
Tran.	75	3T1	-	-	-	151	Failed First Row Spot Welds
Tran.	75	3T2	-	-	-	154	Failed First Row Spot Welds
Tran.	75	3T7	0-130	575	743		Failed First Row Spot Welds
Tran.	75	3T8	0-130	350	557		Failed First Row Spot Welds
Tran.	75	3T9	0-130	-	20		Failed First Row Spot Welds
Tran.	75	3T10	0-130	615	702		Failed First Row Spot Welds
Avg.				513	506	153	
Tran.	-320	3T3	-	-	-	178	Failed First Row Spot Welds
Tran.	-320	3T4	-	1150	-	175	Failed First Row Spot Welds
Tran.	-320	3T11	0-150	-	1204		Failed First Row Spot Welds
Tran.	-320	3T12	0-150	-	894		Failed First Row Spot Welds
Tran.	-320	3T13	0-150	-	691		Failed First Row Spot Welds
Tran.	-320	3T14	0-150	-	773		Failed First Row Spot Welds
Avg.				1150	891	177	
Tran.	-423	3T5	-	-	-	197	Failed First Row Spot Welds
Tran.	-423	3T6	-	-	-	193	Failed First Row Spot Welds
Tran.	-423	3T15	0-166	400	456	-	Failed First Row Spot Welds
Tran.	-423	3T16	0-166	-	437		Failed First Row Spot Welds
Tran.	-423	3T17	0-166	-	195		Failed First Row Spot Welds
Tran.	-423	3T18	0-166	-	743		Failed First Row Spot Welds
Avg.				400	458	195	

Table 20

RESULTS OF STATISTICAL ANALYSIS ON 0.2% OFFSET YIELD STRENGTHS

MATERIAL	TEST TEMP (°F)	GRAIN DIR.	MEAN (KSI)	S	A (KSI)	B (KSI)
304 Stainless Steel	75	Long.	173	2.83	157	163
70 Percent		Trans.	171	1.82	160	164
Cold Rolled	-100	Long.	188	4.56	162	173
		Trans.	193	5.36	162	175
	-320	Long.	208	7.46*	165*	182*
		Trans.	214	2.68	198	205
	-423	Long.	226	9.94*	168*	191*
		Trans.	226	4.00	203	212
18 Percent Nickel	75	Long.	277	1.92	266	270
Maraging Steel		Trans.	277	1.10	270	273
	-100	Long.	293	8.17	246	265
		Trans.	302	1.79	292	296
	-320	Long.	336	3.39	316	324
		Trans.	341	1.67	331	335
	-423	Long.	386	1.30	379	382
		Trans.	388	2.49	374	380
Hastelloy B Nickel	75	Long.	192	1.52	183	186
Alloy, 40 Percent		Trans.	168	2.70	152	158
Cold Rolled	-100	Long.	210	4.04	187	196
		Trans.	185	5.92	151	165
	-320	Long.	237	2.55	222	228
		Trans.	204	8.44*	155*	175*
	-423	Long.	250	4.71	223	234
		Trans.	216	4.38	191	201

Table 20 (Cont.)

RESULTS OF STATISTICAL ANALYSIS ON 0.2% OFFSET YIELD STRENGTHS

MATERIAL	TEST TEMP (°F)	GRAIN DIR.	MEAN (KSI)	S	A (KSI)	B (KSI)
718 Nickel Alloy, 30 Percent Cold Rolled	75	Long.	218	0.89	213	215
		Tran.	206	1.64	196	200
	-100	Long.	230	2.55	215	221
		Tran.	218	3.19	200	207
	-320	Long.	259	1.41	251	254
		Tran.	238	2.35	224	230
	-423	Long.	269	1.34	261	264
		Tran.	251	3.16	233	240
7039-T6 Aluminum Alloy	75	Long.	62.7	0.24	61.3	61.9
		Tran.	59.8	0.14	59.0	59.3
	-100	Long.	66.7	0.23	65.4	65.9
		Tran.	64.6	0.45	62.0	63.0
	-320	Long.	74.4	1.06	68.3	70.8
		Tran,	71.2	0.65	67.5	69.0
	-423	Long.	78.5	0.72	74.4	74.1
		Tran.	75.9	0.53	72.9	

* Value of S Large so that $\overline{X} - K_A S < 0.80\,\overline{X}$ and $\overline{X} - K_B S < 0.88\overline{X}$

Table 21

RESULTS OF STATISTICAL ANALYSIS ON TENSILE STRENGTHS

MATERIAL	TEST TEMP (°F)	GRAIN DIR.	MEAN (KSI)	S	A (KSI)	B (KSI)
304 Stainless	75	Long.	191	1.34	184	187
Steel, 70 Percent		Tran.	209	1.52	200	203
Cold Rolled	-100	Long.	213	2.00	201	206
		Tran.	232	3.12	214	221
	-320	Long.	276	4.44	251	261
		Tran.	271	1.87	260	265
	-423	Long.	292	8.66	248	266
		Tran.	313	2.51	298	304
18 Percent Nickel	75	Long.	283	1.52	275	278
Maraging Steel		Tran.	285	1.14	278	281
	-100	Long.	304	2.17	291	296
		Tran.	311	2.17	299	304
	-320	Long.	351	2.30	337	343
		Tran.	356	0.89	351	353
	-423	Long.	397	0.84	392	394
		Tran.	398	5.87	364	378
Hastelloy B Nickel	75	Long.	206	2.05	194	199
Alloy, 40 Percent		Tran.	200	3.90	177	186
Cold Rolled	-100	Long.	226	3.08	208	215
		Tran.	220	0.45	218	219
	-320	Long.	258	0.89	253	255
		Tran.	248	8.07	201	220
	-423	Long.	282	1.14	276	278
		Tran.	264	3.29	245	253

Table 21 (Cont.)

RESULTS OF STATISTICAL ANALYSIS ON TENSILE STRENGTHS

MATERIAL	TEST TEMP (°F)	GRAIN. DIR.	MEAN (KSI)	S	A (KSI)	B (KSI)
718 Nickel Alloy, 30 Percent Cold Rolled	75	Long.	230	0.89	224	227
		Tran.	223	1.64	214	218
	-100	Long.	249	1.30	241	244
		Tran.	242	0.84	237	239
	-320	Long.	292	1.79	281	286
		Tran.	273	2.95	256	263
	-423	Long.	309	3.46	289	297
		Tran.	295	1.30	288	291
7039-T6 Aluminum Alloy	75	Long.	69.0	0.23	67.6	68.2
		Tran.	68.3	0.09	67.7	68.0
	-100	Long.	74.2	0.11	73.5	73.8
		Tran.	73.8	0.13	73.1	73.4
	-320	Long.	86.0	0.16	85.0	85.4
		Tran.	85.6	0.15	84.7	85.0
	-423	Long.	99.3	0.22	98.1	98.6
		Tran.	97.6	0.88	92.6	94.6

Table 22

RESULTS OF STATISTICAL ANALYSIS ON WELD TENSILE STRENGTHS

MATERIAL	TEST TEMP (°F)	GRAIN DIR.	MEAN (KSI)	S	A (KSI)	B (KSI)
304 Stainless Steel, 70 Percent Cold Rolled (Fusion Weld)	75	Long.	98.2	2.55	83.5	89.4
		Tran.	102	1.10	95.5	98.0
	-100	Long.	177	1.87	166	171
		Tran.	180	0.71	176	178
	-320	Long.	243	1.67	233	237
		Tran.	249	1.14	243	245
	-423	Long.	265	3.44	246	254
		Tran.	290	3.49	270	278
304 Stainless Steel, 70 Percent Cold Rolled (Resistance Seam Weld)	75	Long.	141	0.84	136	138
		Tran.	150	2.88	134	140
	-100	Long.	191	3.16	173	180
		Tran.	196	9.07*	144*	165*
	-320	Long.	231	2.70	216	222
		Tran.	241	8.23	193	212
	-423	Long.	229	5.73	196	210
		Tran.	232	5.67	199	213
18 Percent Nickel Maraging Steel (Fusion Weld)	75	Long.	143	3.81	121	130
		Tran.	142	2.77	126	132
	-100	Long.	171	2.35	157	163
		Tran.	164	1.10	158	160
	-320	Long.	216	2.88	200	206
		Tran.	210	3.97	187	196
	-423	Long.	266	2.97	248	255
		Tran.	261	5.10	232	243

Table 22 (Cont.)

RESULTS OF STATISTICAL ANALYSIS ON WELD TENSILE STRENGTHS

MATERIAL	TEST TEMP (°F)	GRAIN DIR	MEAN (KSI)	S	A (KSI)	B (KSI)
18 Percent Nickel	75	Long.	221	8.23*	173*	192*
Maraging Steel		Tran.	227	8.20*	179*	198*
(Fusion Weld, Aged	-100	Long.	275	5.46	243	256
After Welding)		Tran.	272	8.50	223	243
	-320	Long.	301	25.0*	156*	215*
		Tran.	310	17.0*	212*	252*
	-423	Long.	292	6.02	258	272
		Tran.	305	26.7*	151*	213*
Hastelloy B Nickel	75	Long.	134	3.35	114	122
Alloy, 40 Percent		Tran.	134	3.21	116	123
Cold Rolled	-100	Long.	151	1.79	141	145
(Fusion Weld)		Tran.	155	1.30	148	151
	-320	Long.	179	3.54	159	167
		Tran.	178	0.45	176	177
	-423	Long.	198	3.49	178	186
		Tran.	198	4.16	174	183
718 Nickel Alloy,	75	Long.	113	4.93*	84.1*	95.6*
30 Percent		Tran.	112	6.58	74.4*	89.7*
Cold Rolled	-100	Long.	144	3.85	122	131
(Fusion Weld)		Tran.	130	8.58*	80.6*	101*
	-320	Long.	170	4.04	146	156
		Tran.	145	3.16	127	134
	-423	Long.	154	9.45*	99.0*	121*
		Tran.	146	3.97	123	132

Table 22 (Cont.)

RESULTS OF STATISTICAL ANALYSIS ON WELD TENSILE STRENGTHS

MATERIAL	TEST TEMP (°F)	GRAIN DIR	MEAN (KSI)	S	A (KSI)	B (KSI)
718 Nickel Alloy,	75	Long.	192	2.30	179	184
30 Percent		Tran.	184	1.67	175	179
Cold Rolled	-100	Long.	207	4.56	181	192
(Fusion Weld, Aged		Tran.	201	2.92	184	191
After Welding)	-320	Long.	232	8.38*	183*	203*
		Tran.	228	3.96	205	214
	-423	Long.	258	4.16	234	244
		Tran.	249	3.11	231	238
7039-T6 Aluminum	75	Long.	55.5	1.09	49.2	51.7
Alloy (Fusion		Tran.	54.9	0.34	52.9	53.7
Weld)	-100	Long.	56.3	1.35	48.5	51.7
		Tran.	56.2	1.66	46.6	50.4
	-320	Long.	58.8	5.38*	27.7*	40.3*
		Tran.	58.6	1.78	48.3	52.4
	-423	Long.	51.4	4.72*	24.1*	35.1*
		Tran.	56.9	1.48	48.3	51.8

* Value of S Large so that $\bar{X}-K_AS<0.80\ \bar{X}$ and $\bar{X}-K_BS<0.88\ \bar{X}$

Table 23

RESULTS OF STATISTICAL ANALYSIS ON SPOT WELD TENSION AND SHEAR STRENGTHS

MATERIAL	TEST TEMP (°F)	TEST	MEAN (LB.)	S	A (LB.)	B (LB.)
304 Stainless Steel, 70 Percent Cold Rolled	75	Tension	330	40.4*	196*	252*
		Shear	701	39.5	570	624
	-100	Tension	386	29.4*	290*	330*
		Shear	968	44.7	821	882
	-320	Tension	388	32.8*	280*	325*
		Shear	1157	60.2	959	1042
	-423	Tension	292	35.7*	174*	223*
		Shear	1138	56.1	953	1030
18 Percent Nickel Maraging Steel	75	Tension	470	40.4*	196*	252 *
		Shear	983	101 *	650*	788 *
	-100	Tension	386	29.4*	290*	330 *
		Shear	1169	132 *	736*	916 *
	-320	Tension	552	46.1*	400*	463 *
		Shear	1588	209 *	898*	1185*
	-423	Tension	447	42.2*	308*	366*
		Shear	1605	181 *	1007*	1256*
Hastelloy B Nickel Alloy, 40 Percent Cold Rolled	75	Tension	284	32.6*	176*	221*
		Shear	943	27.4	853	890
	-100	Tension	289	26.8*	200*	237*
		Shear	1004	35.2	888	936
	-320	Tension	312	25.4*	228*	263*
		Shear	1092	21.6	1021	1050
	-423	Tension	327	26.2*	240*	276*
		Shear	1129	66.4	911	1002

Table 23 (Cont.)

RESULTS OF STATISTICAL ANALYSIS ON SPOT WELD TENSION AND SHEAR STRENGTHS

MATERIAL	TEST TEMP (°F)	TEST	MEAN (LB.)	S	A (LB.)	B (LB.)
718 Nickel Alloy, 30 Percent Cold Rolled	75	Tension	446	26.8	358	394
		Shear	689	46.6*	536*	599*
	-100	Tension	451	33.5*	340*	386*
		Shear	726	35.2	610	658
	-320	Tension	457	26.5	370	406
		Shear	807	47.0	652	716
	-423	Tension	423	38.3*	296*	349*
		Shear	882	55.9*	698*	774*
7039-T6 Aluminum Alloy	75	Tension	490	31.8*	385*	429*
		Shear	1212	65.6	996	1086
	-100	Tension	458	23.8	380	413
		Shear	1283	50.1	1118	1186
	-320	Tension	292	23.6*	214*	246*
		Shear	1084	42.0	946	1003
	-423	Tension	239	19.4*	175*	201*
		Shear	1036	51.5	866	937

* Value of S Large so that $\bar{X}-K_AS < 0.80\ \bar{X}$ and $\bar{X}-K_BS < 0.80\ \bar{X}$

Table 24. Crack Propagation Properties of 70 Percent Cold Rolled Type 304 Stainless Steel (0.020 in, Sheet, Allegheny-Ludlum Steel Corp., Heat No. 94997)

Test Temp (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (Ksi)	Net Stress σ_N (Ksi)	Fracture Toughness K_C (Ksi)$\sqrt{in.}$	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	1L1	4.008/.020	1.25	7,700	1.37	95.8	146	149	860
	Long.	1L2	4.010/.020	1.25	7,860	1.55	98.1	160	168	1030
	Long.	1L3	4.010/.020	1.25	7,660	1.55	94.5	155	159	980
	Long.	1L4	4.010/.020	1.24	7,800	1.65	97.0	165	169	1100
	Long.	1L5	4.010/.020	1.22	7,720	1.67	97.3	165	169	1100
	Avg.		4.010/.020	1.24	7,748	1.56	96.5	158	162	1014
75	Trans.	1T1	4.000/.020	1.24	5,180	1.25	65.0	94.3	95.0	322
	Trans.	1T2	4.000/.020	1.24	5,060	1.40	63.7	97.3	99.5	354
	Trans.	1T3	4.004/.020	1.25	5,060	1.27	63.3	92.5	93.8	314
	Trans.	1T4	4.000/.020	1.25	5,360	1.47	66.4	105.0	107.0	408
	Trans.	1T5	4.005/.020	1.25	5,260	1.25	65.8	95.4	96.3	332
	Avg.		4.002/.020	1.25	5,184	1.33	64.8	96.9	98.3	346
-320	Long.	1L6	4.010/.0196	1.23	10,500	1.75	134	237	244	2030
	Long.	1L7	4.010/.0196	1.24	10,500	1.47	134	211	217	1620
	Long.	1L8	4.010/.0198	1.24	10,400	1.75	131	233	228	1790
	Long.	1L9	4.010/.0199	1.24	10,300	1.50	129	206	210	1515
	Long.	1L10	4.010/.0197	1.24	10,100	1.80	128	232	237	1930
	Avg.		4.010/.0197	1.24	10,360	1.65	131	224	227	1777
-320	Trans.	1T6	4.000/.0197	1.26	7,800	1.49	99.1	158	162	875
	Trans.	1T7	4.000/.0197	1.25	7,800	1.60	99.0	165	169	959
	Trans.	1T8	4.010/.020	1.25	8,000	1.55	100	164	167	934
	Trans.	1T9	4.010/.020	1.25	7,900	1.60	98.5	164	168	942
	Trans.	1T10	4.010/.020	1.25	7,760	1.45	96.9	152	155	802
	Avg.		4.004/.0199	1.25	7,852	1.54	98.7	161	164	902

Table 25. Crack Propagation Properties of 18 Percent Nickel Maraging Steel (0.025 in. Sheet, Latrobe Steel Co., Heat No. C56858)

Test Temp (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in.)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (Ksi)	Net Stress σ_N (Ksi)	Fracture Toughness K_C (Ksi)$\sqrt{in.}$	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long	7L1	4.000/.0280	1.24	9,300	1.26	83.0	121	122	580
	Long	7L2	4.000/.0280	1.24	10,000	1.24	89.2	129	130	660
	Long	7L3	4.000/.0275	1.24	9,620	1.24	87.4	126	127	640
	Long	7L4	4.000/.0275	1.24	9,200	1.24	83.8	121	122	582
	Long	7L5	4.000/.0286	1.23	10,100	1.24	88.5	128	129	656
	Avg.		4.000/.0279	1.24	9,644	1.24	86.4	125	126	624
-320	Long	7L6	4.010/.0268	1.24	9,600	1.25	89.5	130	131	622
	Long	7L7	3.945/.0263	1.23	7,940	1.23	76.5	111	120	464
	Long	7L8	4.020/.0263	1.24	9,320	1.24	88.0	127	128	596
	Long	7L9	4.015/.0270	1.24	8,900	1.24	81.9	118	120	524
	Long	7L10	4.020/.0270	1.24	8,920	1.24	82.5	119	120	520
	Avg		4.002/.0267	1.24	8,932	1.24	83.7	121	124	545
-320	Trans.		4.010/.0268	1.24	9,600	1.25	89.5	130	131	622
	Trans.		3.945/.0263	1.23	7,940	1.23	76.5	111	120	462
	Trans.		4.020/.0264	1.24	9,320	1.24	88.0	127	128	596
	Trans.		4.015/.0270	1.24	8,900	1.24	81.9	118	120	524
	Trans.		4.020/.0270	1.24	8,920	1.24	82.5	119	120	520
	Avg.		4.002/.0267	1.24	8,936	1.24	83.7	121	124	545

Table 26-. Crack Propagation Properties of Type 718 Nickel Alloy (0.025 in. Sheet, Huntington Division of International Nickel Co., Heat No. 6807EV)

Test Temp (°F)	Dir.	W/T	Initial Notch Length (in.)	Critical Load (lbs)	Critical Crack Length (in.)	Gross Stress α_G (Ksi)	Net Stress α_N (Ksi)	Fracture Toughness K_C (Ksi)$\sqrt{in.}$	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	4.002/.0280	1.25	12,500	1.55	112	182	187	1150
	Long.	4.000/.0283	1.25	12,600	1.45	111	175	178	1040
	Long.	4.005/.0283	1.24	12,800	1.55	112	182	187	1150
	Long.	4.003/.0280	1.23	13,000	1.48	116	184	188	1170
	Long.	4.010/.0280	1.24	12,350	1.46	110	173	177	1040
	Avg.	4.004/.0282	1.24	12,650	1.50	112	179	183	1110
75	Trans.	3.963/.0276	1.24	11,900	1.24	110	160	161	852
	Trans.	3.980/.0274	1.24	11,900	1.30	109	163	164	890
	Trans.	3.975/.0280	1.24	12,200	1.35	110	166	168	930
	Trans.	4.015/.0282	1.24	12,300	1.51	109	175	179	1060
	Trans.	4.010/.0282	1.24	12,400	1.48	110	174	178	1050
	Avg.	3.989/.0277	1.24	12,140	1.38	110	168	170	956
-320	Long.	4.010/.0278	1.23	14,200	1.40	127	204	200	1250
	Long.	4.005/.0274	1.25	13,800	1.40	126	193	197	1210
	Long.	4.010/.0280	1.25	14,500	1.45	129	201	203	1330
	Long.	4.005/.0278	1.25	13,300	1.45	119	197	191	1140
	Avg.	4.008/.0278	1.25	13,950	1.43	125	199	198	1233
-320	Trans.	4.015/.0275	1.25	13,000	1.40	118	180	185	1080
	Trans.	4.015/.0277	1.24	12,900	1.42	116	179	183	1060
	Trans.	4.020/.0273	1.25	12,900	1.37	118	179	183	1060
	Trans.	4.020/.0275	1.27	13,000	1.45	117	184	188	1200
	Trans.	4.015/.0277	1.26	13,100	1.50	118	188	192	1160
	Avg.	4.017/.0275	1.25	12,980	1.43	117	182	186	1112

Table 27. Crack Propagation Properties of Hastelloy B (0.020 in. Sheet, Wallingford Steel Co.)

Test Temp (°F)	Dir.	W/T	Initial Notch Length (In.)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (Ksi)	Net Stress σ_N (Ksi)	Fracture Toughness K_C (Ksi)$\sqrt{\text{in.}}$	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	4.010/.0194	1.26	7,940	1.34	102	153	156	850
	Long	4.015/.0213	1.25	8,840	1.43	104.0	160	166	940
	Long.	4.005/.0197	1.25	7,600	1.32	96.5	144	146	780
	Long.	4.010/.0197	1.25	7,740	1.50	98.0	157	160	910
	Long.	4.005/.0197	1.24	7,880	1.42	100	155	158	868
	Avg.	4.009/.0199	1.25	8,000	1.40	100	154	157	870
75	Trans.	4.023/.020	1.23	7,220	1.60	89.7	149	153	790
	Trans.	4.048/.020	1.22	7,460	1.52	92.5	147	153	781
	Trans.	4.034/.0199	1.25	7,100	1.40	88.5	130	134	600
	Trans.	4.000/.0197	1.24	7,000	1.60	89.0	148	152	770
	Trans.	4.024/.0198	1.25	7,040	1.61	88.5	148	151	770
	Avg.	4.026/.0199	1.24	7,164	1.55	89.6	144	149	742
-320	Long.	4.010/.0192	1.25	9,900	1.47	130	205	205	1460
	Long.	4.010/.0196	1.25	9,940	1.47	127	200	204	1380
	Long.	4.010/.0194	1.24	9,640	1.70	124	215	221	1650
	Long.	4.020/.0193	1.24	9,800	1.65	121	214	214	1580
	Long.	4.010/.0195	1.25	9,780	1.50	124	199	203	1370
	Avg.	4.012/.0194	1.25	9,812	1.56	125	207	209	1488
-320	Trans.	4.025/.0194	1.26	9,100	1.47	117	184	188	1170
	Trans.	4.090/.0195	1.26	9,140	1.39	115	174	178	1050
	Trans	4.035/.0196	1.25	8,740	1.60	111	183	189	1190
	Trans.	4.060/.0194	1.25	8,800	1.50	112	172	182	1100
	Trans.	4.065/.0194	1.25	8,860	1.55	112	181	182	1130
	Avg.	4.055/.0195	1.25	8,928	1.50	113	179	184	1128

Table 28. Crack Propagation Properties of Rene 41 Alloy (0.020 in. Sheet, Union Carbide Stellite, Heat No. T2-8259)

Test Temp (°F)	Dir.	W/T	Initial Notch Length (in.)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress α_G (Ksi)	Net Stress α_N (Ksi)	Fracture Toughness K_C (Ksi)$\sqrt{in.}$	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	4.000/.0205	1.25	6,900	2.12	84.3	159	173	674
	Long.	4.000/.0205	1.23	6,760	1.32	82.4	123	124	526
	Long.	4.000/.0205	1.23	6,720	1.39	82.0	126	128	560
	Long.	4.000/.0206	1.23	6,620	1.95	80.3	156	157	841
	Long.	4.000/.0205	1.24	6,520	1.90	79.6	151	153	803
	Avg.	4.000/.0205	1.24	6,704	1.74	81.7	143	147	681
75	Trans.	4.000/.0215	1.25	7,200	1.55	83.8	137	140	708
	Trans.	4.000/.0210	1.25	7,000	1.50	81.3	137	132	627
	Trans.	4.000/.0212	1.25	7,100	1.69	84.0	145	148	791
	Trans.	4.000/.0210	1.26	7,000	1.67	83.4	143	146	770
	Trans.	4.000/.0210	1.23	6,900	1.70	82.2	143	146	773
	Avg.	4.000/.0212	1.25	7,040	1.62	82.9	141	142	734

Table 29. Crack Propagation Properties of 7039-T6 Aluminum Alloy (0.063 in. Sheet, Kaiser Aluminum Co.)

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{\text{in.}}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	5L1	4.010/.0600	1.23	8240	2.00	34.3	68.3	68.5	480
	Long.	5L2	4.010/.0603	1.23	8480	1.95	35.0	68.2	68.2	465
	Long.	5L3	4.015/.0600	1.22	10000	1.48	41.7	65.6	67.3	467
	Long.	5L4	4.010/.0600	1.21	9980	1.55	41.5	67.5	68.6	480
	Long.	5L5	4.010/.0598	1.21	9880	1.70	41.2	71.5	73.0	545
	Avg.		4.012/.0600	1.22	9316	1.74	38.7	68.2	69.1	487
75	Trans.	5T1	4.010/0.0593	1.24	8300	1.90	35.3	67.2	67.5	451
	Trans.	5T2	4.010/0.0594	1.23	8360	1.90	35.2	67.0	67.5	453
	Trans.	5T3	4.010/0.0600	1.23	9500	1.53	39.6	64.0	65.0	420
	Trans.	5T4	4.010/0.0602	1.23	9400	1.52	39.0	62.7	64.0	407
	Trans.	5T5	4.010/0.0598	1.23	9400	1.62	38.9	65.2	66.7	444
	Avg.		4.010/.0597	1.23	8992	1.69	37.6	65.2	66.1	435
-320	Long.	5L6	4.010/0.0596	1.24	8560	1.37	35.9	54.5	55.0	242
	Long.	5L7	4.010/0.0594	1.23	8500	1.52	35.8	51.5	63.0	242
	Long.	5L8	4.005/0.0594	1.24	6840	1.31	28.8	42.7	43.0	133
	Long.	5L9	4.010/0.0600	1.24	6700	1.32	27.9	41.5	42.0	143
	Long.	5L10	4.016/0.0600	1.24	6700	1.32	27.9	41.5	42.0	146
	Avg.		4.010/.0597	1.24	7460	1.37	31.3	46.3	49.0	181
-320	Trans.	5T6	4.010/.0595	1.23	7900	1.45	33.1	51.9	52.5	242
	Trans.	5T7	4.013/.0600	1.22	7700	1.52	32.0	51.5	52.5	242
	Trans.	5T8	4.010/.0597	1.24	6100	1.25	25.6	37.2	37.4	133
	Trans.	5T9	4.010/.0597	1.23	6400	1.32	26.8	40.0	40.4	143
	Trans.	5T10	4.010/.0595	1.24	6580	1.35	26.8	40.3	40.8	146
	Avg.		4.011/.0597	1.23	6896	1.38	28.9	44.2	44.7	181

Table 30. Crack Propagation Properties of 2219-T81 Aluminum Alloy (0.063 in. Sheet, Aluminum Co. of America)

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	2L1	4.020/.0613	1.25	8100	1.50	32.9	52.5	53.7	298
	Long.	2L2	4.000/.0614	1.25	8060	1.69	32.9	57.0	58.3	351
	Long.	2L3	4.000/.0620	1.25	8240	1.70	33.2	58.0	59.2	362
	Long.	2L4	4.000/.0614	1.25	8300	1.97	33.8	66.5	68.0	477
	Long.	2L5	4.000/.0630	1.25	8260	1.67	33.4	57.2	58.5	355
	Avg.		4.004/.0618	1.25	8192	1.71	33.2	58.2	59.5	369
75	Trans.	2T7	4.015/.0613	1.24	7680	1.70	31.3	54.3	55.7	320
	Trans.	2T10	4.015/.0613	1.24	7720	1.65	31.5	53.3	54.7	309
	Trans.	2T12	4.015/.0616	1.24	8060	1.65	32.6	55.2	56.8	332
	Trans.	2T13	4.015/.0614	1.24	8100	1.65	33.0	55.8	57.4	340
	Avg.		4.015/.0614	1.24	7890	1.66	32.1	54.7	56.2	325
-320	Long.	2L16	4.010/.0616	1.24	9700	1.56	39.3	64.3	66.1	393
	Long.	2L7	4.005/.0617	1.25	9720	1.67	39.4	67.6	68.6	423
	Long.	2L8	4.010/0015	1.26	9780	1.38	39.7	60.5	61.6	343
	Long.	2L9	4.010/.0615	1.24	9720	1.65	39.4	67.0	68.7	424
	Long.	2L10	4.005/.0617	1.25	9460	1.66	38.3	65.3	67.1	406
	Avg.		4.008/.0616	1.25	9676	1.58	39.2	64.9	66.4	398
-320	Trans.	2T6	4.010/.0614	1.23	8920	1.57	36.3	59.6	61.3	342
	Trans.	2T7	4.010/.0614	1.24	9200	1.60	37.4	62.2	64.0	372
	Trans.	2T8	4.010/.0613	1.24	8880	1.58	36.2	59.7	61.3	341
	Trans.	2T9	4.010/.0613	1.24	8780	1.65	35.7	60.6	62.1	350
	Avg.		4.010/.0614	1.24	8945	1.60	36.4	60.5	62.2	351

Table 31. Crack Propagation Properties of Titanium-6Al-4V ELI Alloy
(0.025 in. Sheet, Titanium Metals Corp. of America, Heat No. D-2133)

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress α_G (ksi)	Net Stress α_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	4L1	4.040/.0245	1.27	7400	1.65	74.9	126	130	1060
	Long.	4L2	4.025/.0247	1.27	7300	1.53	73.6	119	122	930
	Long.	4L3	4.000/.0250	1.27	7180	1.60	71.8	119	123	950
	Long.	4L4	4.000/.0250	1.28	6840	1.70	68.5	119	122	930
	Long.	4L5	4.000/.0250	1.26	7060	1.65	70.6	120	123	869
	Avg.		4.012/.0249	1.27	7156	1.63	71.9	121	124	948
75	Trans.	4T1	3.983/.0242	1.24	6360	1.55	66.2	109	110	775
	Trans.	4T2	3.960/.0240	1.23	6400	1.47	67.3	107	109	759
	Trans.	4T3	3.950/.0240	1.23	6300	1.40	66.4	103	104	690
	Trans.	4T4	4.000/.0260	1.23	6320	1.55	61.8	99.3	103	690
	Trans.	4T5	4.005/.0250	1.23	6140	1.60	61.5	102	105	701
	Avg.		3.980/.0246	1.23	6304	1.51	64.6	104	106	723
-320	Long.	4L6	4.010/.0250	1.28	5240	1.32	52.5	77.9	77.9	360
	Long.	4L7	4.010/.0250	1.28	5360	1.30	53.5	79.1	80.3	373
	Long.	4L8	4.010/.0250	1.28	5240	1.35	52.3	77.9	80.5	343
	Long.	4L9	4.005/.0250	1.30	5300	1.35	53.0	77.9	81.8	388
	Long.	4L10	4.000/.0250	1.27	5380	1.40	53.7	82.8	84.4	514
	Avg.		4.007/.0250	1.28	5304	1.34	53.0	79.1	81.0	396
-320	Trans.	4T6	4.000/0.246	1.23	6040	1.34	61.5	92.5	90.4	514
	Trans.	4T7	4.000/0.250	1.24	6440	1.28	64.4	94.8	95.3	529
	Trans.	4T8	4.000/0.250	1.24	6160	1.45	61.7	96.8	97.6	557
	Trans.	4T9	4.010/0.250	1.25	6340	1.34	63.2	94.8	96.5	544
	Trans.	4T10	4.000/0.247	1.24	6000	1.33	60.7	91.0	91.5	487
	Avg.		4.002/.0249	1.24	6196	1.35	62.3	94.0	94.3	526

Table 32. Effect of Initial Notch Length of Crack Propagation Properties of 75 percent Cold Rolled Type 310 Stainless Steel. (0.020 in. Sheet, Washington Steel Corporation, Heat No. 43631.)

Test Temp. (°F)	Dir.	Notch Length (in)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress α_G (ksi)	Net Stress α_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	0.75	4.005/.0190	0.74	7900	0.90	104	134	126	626
	Long.	0.75	4.005/.0190	0.74	8140	0.90	107	138	130	665
	Long.	0.75	4.005/.0190	0.74	7720	0.95	101	133	126	626
	Long.	0.75	4.005/.0194	0.74	7900	0.87	102	141	122	586
	Long.	0.75	4.010/.0192	0.74	8120	1.12	105	146	145	826
	Avg.		4.006/.0191	0.74	7956	0.95	104	138	130	666
-320	Long.	0.75	4.000/.0191	0.75	11300	0.98	148	196	188	1339
	Long.	0.75	4.000/.0192	0.74	11200	0.98	146	193	185	1300
	Long.	0.75	4.000/.0190	0.74	10800	1.00	142	190	182	1255
	Long.	0.75	4.010/.0190	0.75	10800	0.95	142	187	177	1190
	Long.	0.75	4.010/.0190	0.75	11200	1.00	147	196	188	1339
	Avg.		4.002/.0191	0.75	11060	0.98	145	192	184	1285
75	Long	1.75	4.005/.0190	1.76	4500	2.01	59.3	119	119	558
	Long	1.75	4.005/.0190	1.75	4820	2.12	63.5	135	134	708
	Long.	1.75	4.035/.0190	1.75	4500	2.05	59.0	120	120	568
	Long.	1.75	3.980/.0190	1.75	4420	2.13	58.3	126	121	578
	Long.	1.75	4.005/.0190	1.74	4700	2.10	62.0	130	129	655
	Avg.		4.006/.0190	1.75	4588	2.08	60.4	126	125	613
-320	Long.	1.75	4.010/.0191	1.74	6320	2.00	82.7	165	165	1032
	Long.	1.75	4.010/.0190	1.75	6100	1.98	80.0	158	159	958
	Long.	1.75	4.000/.0190	1.74	6400	2.00	84.3	168	168	1070
	Long.	1.75	4.010/.0190	1.74	6300	2.00	82.6	165	165	1032
	Long.	1.75	4.000/.0194	1.75	6400	2.00	84.2	168	168	1070
	Avg.		4.006/.0191	1.75	6304	2.00	82.8	165	165	1032

Table 33. Effect of Initial Notch Length on Crack Propagation Properties of Type 718 Nickel Alloy. (0.025 in. Sheet, Huntington Division International Nickel Company, Heat No. 6807EV).

Test Temp. (°F)	Dir.	Notch Length (in)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	0.75	4.010/.0280	0.74	15500	0.88	138	177	165	900
	Long.	0.75	4.008/.0276	0.73	16300	1.00	148	197	190	1190
	Long.	0.75	4.008/.0280	0.72	16200	0.94	145	189	180	1070
	Long.	0.75	4.010/.0280	0.72	16100	0.89	143	184	173	988
	Long.	0.75	4.000/.0283	0.73	15600	1.05	138	187	183	1100
	Avg.		4.007/.0280	0.73	15940	95.2	142	187	178	1050
-320	Long.	0.75	4.000/.0280	0.73	19200	0.83	171	216	199	1240
	Long.	0.75	4.000/.0280	0.73	18900	0.93	169	220	209	1370
	Long.	0.75	-	-	-	-	-	-	-	-
	Long.	0.75	4.010/.0280	0.73	19100	0.85	170	215	201	1260
	Long.	0.75	4.010/.0275	0.74	19500	0.95	177	232	221	1525
	Avg.		4.005/.0279	0.73	19175	0.89	172	221	208	1349
75	Long.	1.75	4.008/.0283	1.73	9060	2.10	80.1	168	170	954
	Long.	1.75	4.007/.0276	1.72	9480	1.95	85.8	167	168	932
	Long.	1.75	4.003/.0280	1.73	9300	1.98	83.0	164	164	890
	Long.	1.75	4.004/.0276	1.72	9020	2.10	81.8	172	171	965
	Long.	1.75	4.005/.0283	1.72	9660	2.15	85.5	185	181	1080
	Avg.		4.006/.0280	1.72	9304	2.06	83.2	171	171	944
-320	Long.	1.75	4.010/.0280	1.72	10300	1.95	91.9	179	180	1013
	Long.	1.75	4.010/.0280	1.73	10000	1.79	89.1	167	164	843
	Long.	1.75	4.010/.0280	1.73	10300	2.00	91.9	183	184	1055
	Long.	1.75	4.010/.0280	1.73	10300	1.92	92.0	176	169	945
	Long.	1.75	4.010/.0280	1.72	10100	2.00	90.3	180	181	1022
	Avg.		4.010/.0280	1.72	10200	1.93	91.0	177	176	976

Table 34. Effect of Initial Notch Length on Crack Propagation Properties of 2219-T81 Aluminum Alloy. (0.063 in. Sheet, Aluminum Company of America.

Test Temp. (°F)	Dir.	Notch Length (in)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{\text{in.}}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	0.75	4.01/.0615	0.74	9860	1.16	40.0	56.3	55.6	320
	Long.	0.75	4.00/.0615	0.74	9920	1.12	40.3	56.0	55.0	312
	Long.	0.75	4.01/.0616	0.74	9600	0.95	39.0	51.1	48.7	246
	Long.	0.75	4.00/.0615	0.76	9960	1.10	40.5	55.8	55.2	361
	Long.	0.75	4.01/.0613	0.74	9900	1.11	40.3	55.8	55.0	312
	Avg.		4.01/.0615	0.74	9848	1.09	40.0	55.0	53.9	310
-320	Long.	0.75	4.01/.0610	0.75	11500	0.99	47.1	62.5	60.0	325
	Long.	0.75	4.01/.0610	0.73	11500	1.07	47.1	64.2	62.9	355
	Long.	0.75	4.01/.0610	0.74	11600	1.25	47.8	69.5	69.8	439
	Long.	0.75	4.01/.0610	0.75	11900	1.15	48.8	68.3	67.9	415
	Long.	0.75	4.01/.0610	0.75	11800	1.15	48.3	67.6	67.2	406
	Avg.		4.01/.0610	0.74	11660	1.12	47.8	66.4	65.6	388
75	Long.	1.75	4.015/.0618	1.76	6600	2.10	26.7	56.0	56.0	324
	Long.	1.75	4.000/.0600	1.76	6500	1.95	27.1	53.0	53.1	291
	Long.	1.75	4.000/.0618	1.75	6280	2.05	25.4	52.2	51.6	274
	Long.	1.75	4.000/.0618	1.76	6700	2.06	27.1	56.9	55.6	319
	Long.	1.75	4.000/.0616	1.74	6660	2.08	26.9	56.3	53.7	298
	Avg.		4.003/.0614	1.75	6548	2.05	26.6	54.9	54.0	301
-320	Long.	1.75	4.00/.0614	1.74	7680	2.05	31.3	64.2	64.0	369
	Long.	1.75	4.00/.0610	1.76	7500	2.02	30.7	62.1	62.0	347
	Long.	1.75	4.00/.0610	1.76	7540	2.10	30.9	65.1	64.3	372
	Long.	1.75	4.00/.0610	1.74	7680	2.15	27.3	59.2	57.9	301
	Long.	1.75	4.00/.0610	1.75	7660	2.17	31.4	68.6	67.2	406
	Avg.		4.00/.0611	1.75	7612	2.10	30.3	63.8	63.1	359

Table 35. Effect of Width on Crack Propagation Properties of 70 percent Cold Rolled Type 304 Stainless Steel. (0.020 in. Sheet, Allegheny-Ludlum Steel Corporation, Heat No. 94997).

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (In. lb/in^2)
75	Long.	1L1	2.000/.0198	0.48	5340	0.60	135	193	135	705
	Long.	1L2	2.000/.0198	0.48	5260	0.59	133	189	132	670
	Long.	1L3	2.000/.0198	0.46	5420	0.59	137	195	137	725
	Long.	1L4	2.000/.0198	0.48	5420	0.65	137	202	138	737
	Long.	1L5	2.000/.0198	0.48	5400	0.60	137	195	137	720
	Avg.		2.000/.0198	0.48	5368	0.61	136	195	136	711
-320	Long.	1L6	2.000/.0194	0.49	6840	0.60	176	250	176	1065
	Long.	1L7	2.000/.0198	0.49	7000	0.52	177	239	190	1240
	Long.	1L8	2.000/.0197	0.47	6600	0.60	168	239	167	965
	Long.	1L9	2.000/.0198	0.48	6820	0.60	172	236	172	1020
	Long.	1L10	2.000/.0198	0.48	6800	0.64	172	251	180	1112
	Avg.		2.000/.0197	0.48	6812	0.59	173	243	177	1080

Table 36. Effect of Width on Crack Propagation Properties of 18 percent Nickel Maraging Steel. (0.025 in. Sheet, Latrobe Steel Company, Heat No. C56858).

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress α_G (ksi)	Net Stress α_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	7L1	2.010/.0256	0.58	6440	0.58	125	175	126	620
	Long.	7L2	2.015/.0252	0.55	6880	0.55	136	185	143	795
	Long.	7L3	2.020/.0252	0.58	6600	0.58	130	182	131	668
	Long.	7L4	2.020/.0256	0.58	6940	0.60	134	191	134	700
	Long.	7L5	2.020/.0253	0.58	6780	0.58	133	182	134	700
	Avg.		2.017/.0254	0.57	6728	0.58	132	183	134	697
-320	Long.	7L6	2.020/.0250	0.60	7000	0.60	138	192	138	680
	Long.	7L7	2.015/.0250	0.58	6600	0.58	131	183	133	630
	Long.	7L8	2.020/.0250	0.59	7580	0.59	150	211	152	820
	Long.	7L9	2.020/.0250	0.59	7120	0.59	141	199	143	730
	Long.	7L10	2.020/.0250	0.59	7140	0.59	141	199	143	730
	Avg.		2.019/.0250	0.59	7088	0.59	140	197	142	718

Table 37. Effect of Width on Crack Propagation Properties of Type 718 Nickel Alloy. (0.025 in. Sheet, Huntington Division of International Nickel Company, Heat No. 6807EV).

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	New Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
-320	Long.	8L6	2.010/.0274	0.60	9400	0.67	171	256	182	1035
	Long.	8L7	2.000/.0277	0.61	9320	0.75	169	270	193	1165
	Long.	8L8	2.000/.0277	0.60	9360	0.70	169	260	191	1136
	Long.	8L9	2.000/.0277	0.61	9400	0.70	169	260	191	1136
	Long.	8L10	2.000/.0279	0.61	9300	0.78	168	273	199	1240
	Avg.		2.002/.0276	0.61	9356	0.72	169	264	191	1142

Table 38. Effect of Width on Crack Propagation Properties of Hastelloy B. (0.020 in. Sheet, Wallingford Steel Company.)

Test Temp. (°F)	Dir.	Spec. no.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in.lb/in^2)
75	Long.	9L1	2.000/.0193	0.57	5060	0.70	131	200	144	720
	Long.	9L2	2.000/.0192	0.57	5040	0.75	132	210	151	790
	Long.	9L3	2.000/.0192	0.57	5100	0.75	132	210	152	800
	Long.	9L4	2.010/.0192	0.57	5120	0.72	133	203	150	780
	Long.	9L5	2.000/.0192	0.57	5060	0.70	132	201	145	700
	Avg.		2.002/.0192	0.57	5076	0.72	132	205	148	758
-320	Long.	9L6	2.000/.0198	0.58	6200	0.70	156	240	172	985
	Long.	9L7	2.000/.0190	0.58	6200	0.70	163	250	180	1075
	Long.	9L8	2.010/.0192	0.58	6200	0.70	161	246	177	1040
	Long.	9L9	2.000/.0190	0.58	6160	0.70	162	249	178	1050
	Long.	9L10	2.000/.0190	0.58	6200	0.72	163	254	184	1130
	Avg.		2.002/.0195	0.58	6192	0.70	161	248	178	1056

Table 39. Effect of Width on Crack Propagation Properties of Rene' 41 Alloy. (0.020 in. Sheet, Union Carbide Stellite, Heat No. T2-8259).

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	3L1	2.000/.0210	0.45	4460	0.68	106	170	115	450
	Long.	3L2	2.000/.0215	0.48	4620	0.75	108	172	125	535
	Long.	3L3	2.000/.0210	0.47	4420	0.80	105	175	126	543
	Long.	3L4	2.000/.0213	0.48	4540	0.75	107	170	122	509
	Long.	3L5	2.000/.0215	0.48	4580	0.80	107	178	128	510
	Avg.		2.000/.0212	0.47	4524	0.76	107	173	123	509
-320	Long.	3L6	2.000/.0215	0.48	4940	0.48	115	151	129	550
	Long	3L7	2.000/.0211	0.48	4900	0.55	126	160	122	490
	Long.	3L8	2.000/.0213	0.51	4920	0.51	115	155	127	530
	Long.	3L9	2.000/.0208	0.49	4920	0.58	118	167	120	475
	Long.	3L10	2.000/.0208	0.49	4900	0.60	118	168	118	460
	Avg.		2.000/.0211	0.49	4916	0.54	118	160	123	501

Table 40. Effect of Width on Crack Propagation Properties of 7039-T6 Aluminum Alloy. (0.063 in. Sheet, Kaiser Aluminum Company).

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	5L2	2.000/.0600	0.59	5260	0.78	43.8	72.0	52.0	270
	Long.	5L3	2.000/.0600	0.59	5200	0.68	43.3	62.8	51.2	267
	Long.	5L5	2.000/.0600	0.58	5240	0.85	43.6	75.7	53.2	283
	Long.	5L6	2.000/.0600	0.58	5240	0.85	43.6	75.7	53.2	283
	Long.	5L7	2.000/.0600	0.60	5200	0.77	43.3	70.3	50.5	270
	Avg.		2.000/.0600	0.59	5228	0.79	43.5	71.3	52.0	275
-320	Long.	5L8	2.000/.0600	0.60	4400	0.66	36.7	54.7	39.1	134
	Long.	5L9	2.000/.0600	0.59	4380	0.68	36.0	53.5	39.0	133
	Long.	5L10	2.000/.0600	0.60	4260	0.72	35.5	55.4	40.0	140
	Long.	5L11	2.000/.0600	0.61	4340	0.68	36.0	54.7	39.0	133
	Long.	5L12	2.000/.0600	0.60	4360	0.68	36.4	55.0	32.3	135
	Avg.		2.000/.0600	0.60	4348	0.68	36.1	54.7	37.9	135

Table 41. Effect of Width on Crack Propagation Properties of 2219-T81 Aluminum Alloy. (0.063 in. Sheet, Aluminum Company of America).

Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress α_G (ksi)	Net Stress α_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	2L1	2.000/.0610	0.48	4600	0.80	37.6	62.7	45.3	211
	Long.	2L2	2.000/.0610	0.46	4600	0.75	37.7	60.3	43.2	194
	Long.	2L3	2.000/.0610	0.46	4640	0.80	38.0	63.3	45.5	214
	Long.	2L4	2.000/.0610	0.47	4700	0.75	38.5	61.5	44.2	201
	Long.	2L5	2.000/.0612	0.44	4720	0.90	39.8	70.0	50.5	258
	Avg.		2.000/.0610	0.46	4652	0.80	38.3	63.6	45.7	216
-320	Long.	2L6	2.000/.0610	0.48	5520	0.63	45.2	66.0	51.0	234
	Long.	2L7	2.000/.0610	0.49	5300	0.65	43.0	65.3	46.3	193
	Long.	2L8	2.000/.0610	0.49	5300	0.65	43.0	65.3	46.3	193
	Long.	2L9	2.000/.0610	0.49	5600	0.67	45.8	70.0	48.8	214
	Long.	2L10	2.000/.0610	0.48	5540	0.70	45.4	69.7	49.9	224
	Avg.		2.000/.0610	0.48	5532	0.66	44.5	67.3	48.5	212

Table 42. Effect of Width on Crack Propagation Properties of Titanium-6AL-4V ELI Alloy. (0.025 in. Sheet, Titanium Metals Corporation of America, Heat No. D-2133.)

Test Temp. (°F)	Dir.	Spec. No.	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	4L1	2.000/.0250	0.48	5260	0.70	105	162	116	840
	Long.	4L2	2.000/.0250	0.48	5200	0.80	104	173	125	975
	Long.	4L3	2.000/.0250	0.48	5200	0.75	104	167	119	885
	Long.	4L4	2.000/.0250	0.49	5200	0.78	104	170	123	946
	Long.	4L5	2.000/.0250	0.47	5360	0.75	107	172	123	946
	Avg.		2.000/.0250	0.48	5244	0.76	105	169	121	918
-320	Long.	4L6	2.000/.0243	0.49	4380	0.49	90.0	119	102	590
	Long.	4L7	2.000/.0250	0.50	4380	0.60	88.0	125	88.0	448
	Long.	4L8	2.000/.0250	0.50	4360	0.50	87.4	116	95.5	526
	Long.	4L9	2.000/.0250	0.50	4320	0.50	86.5	115	94.5	517
	Long.	4L10	2.000/.0250	0.49	4320	0.49	86.5	114	94.5	517
	Avg.		2.000/.0249	0.50	4352	0.52	87.7	118	94.9	520

Table 43. Effect of Load Rate on Crack Propagation Properties of 75 percent Cold Rolled Type 310 Stainless Steel. (0.020 in. Sheet, Washington Steel Corporation, Heat No. 43631).

Test Temp. (°F)	Dir.	Load Rate (in/min)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	.01	4.010/.0190	1.24	5840	1.60	76.5	127	131	637
	Long.	.01	4.010/.0192	1.24	6180	1.62	79.0	133	136	728
	Long.	.01	4.005/.0190	1.24	5620	1.48	74.0	117	120	566
	Long.	.01	4.005/.0190	1.23	5580	1.70	73.4	127	131	670
	Long.	.01	4.005/.0190	1.25	5700	150	75.0	120	122	586
	Avg.		4.007/.0191	1.24	5784	1.58	75.6	125	128	637
-320	Long.	.01	4.030/.0190	1.24	8020	1.54	105	169	174	1141
	Long.	.01	4.000/.0192	1.23	8380	1.35	109	165	178	1200
	Long.	.01	4.010/.0191	1.25	8220	1.52	108	173	177	1192
	Long.	.01	4.040/.0190	1.25	8120	1.53	106	170	175	1170
	Long.	.01	4.010/.0190	1.24	8260	1.48	109	172	176	1173
	Avg.		4.018/.0191	1.24	8200	1.48	107	170	176	1175
75	Long.	1.0	4.000/.0190	1.24	6500	1.42	85.2	132	134	710
	Long.	1.0	4.000/.0190	1.24	6100	1.46	80.4	127	130	660
	Long.	1.0	4.005/.0190	1.24	6240	1.35	82.0	123	125	619
	Long.	1.0	4.047/.0190	1.24	6300	1.35	82.2	123	126	620
	Long.	1.0	4.019/.0190	1.24	6200	1.40	81.5	125	123	599
	Avg.		4.014/.0190	1.24	6268	1.40	82.3	126	128	642
-320	Long.	1.0	4.010/.0190	1.23	8200	1.40	108	165	169	1082
	Long.	1.0	4.005/.0193	1.24	8500	1.32	110	164	166	1048
	Long.	1.0	4.020/.0190	1.24	7900	1.45	104	162	165	1032
	Long.	1.0	4.015/.0190	1.25	7700	1.29	101	149	150	850
	Long.	1.0	4.015/.0190	1.24	8140	1.37	111	168	171	1100
	Avg.		4.013/.0191	1.24	8148	1.37	107	162	164	1022

Table 43. (Cont)

Test Temp. (°F)	Dir.	Load Rate (in/min)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	10.0	4.010.0191	1.23	6840	1.29	89.5	132	132	686
	Long.	10.0	4.000/.0193	1.24	6820	1.32	88.5	132	134	702
	Long.	10.0	4.010/.0190	1.30	6740	1.34	88.5	133	129	656
	Long.	10.0	4.005/.0190	1.24	6560	1.34	86.5	130	126	627
	Long.	10.0	4.005/.0190	1.25	5520	1.38	72.5	111	113	499
	Avg.		4.006/.0191	1.25	6496	1.33	85.1	128	127	634
-320	Long.	10.0	4.005/.0192	1.24	6700	1.24	87.0	126	127	608
	Long.	10.0	4.005/.0190	1.24	7100	1.24	93.2	135	136	700
	Long.	10.0	4.010/.0190	1.24	7840	1.35	103	155	158	939
	Long.	10.0	4.010/.0190	1.24	7240	1.30	95.0	140	142	765
	Long.	10.0	4.010/.0190	1.24	7600	1.35	100	150	153	887
	Avg.		4.008/.0190	1.24	7296	1.30	95.6	141	145	780

Table 44. Effect of Load Rate on Crack Propagation Properties of Type 718 Nickel Alloy. (0.025 in. Sheet, Huntington Division International Nickel Company, Heat No. 6807EV).

Test Temp. (°F)	Dir.	Load Rate (in/min)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress α_G (ksi)	Net Stress α_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	.01	4.005/.0280	1.24	12500	1.50	112	178	182	1090
	Long.	.01	4.010/.0280	1.24	12700	1.38	114	172	187	1149
	Long.	.01	4.005/.0280	1.23	12500	1.62	112	188	192	1219
	Long.	.01	4.005/.0280	1.25	12500	1.55	112	182	185	1130
	Long.	.01	4.010/.0280	1.24	12100	1.70	108	187	192	1219
	Avg.		4.007/.0280	1.24	12400	1.55	112	181	188	1161
-320	Long.	.01	4.010/.0278	1.24	13500	1.54	121	197	201	1270
	Long.	.01	4.010/.0278	1.25	13700	1.60	127	210	213	1469
	Long.	.01	4.005/.0276	1.25	13600	1.53	123	199	202	1289
	Long.	.01	4.010/.0280	1.24	13600	1.55	122	198	201	1268
	Long.	.01	4.010/.0280	1.24	13900	1.53	124	200	204	1308
	Avg.		4.008/.0277	1.24	13660	1.55	123	201	204	1321
75	Long.	1.0	4.000/.0282	1.24	12800	1.35	113	171	174	995
	Long.	1.0	4.005/.0282	1.23	12700	1.78	113	202	203	1400
	Long.	1.0	4.000/.0281	1.23	12500	1.60	111	185	190	1190
	Long.	1.0	4.005/.0284	1.23	12500	1.60	110	183	188	1168
	Avg.		4.002/,0282	1.23	12600	1.58	112	185	189	1188
-320	Long.	1.0	4.000/.0280	1.23	13700	1.37	122	186	187	1092
	Long.	1.0	4.010/.0280	1.24	13500	1.37	120	182	186	1075
	Long.	1.0	4.010/.0280	1.23	13400	1.30	120	177	185	1072
	Long.	1.0	4.010/.0280	1.22	14300	1.40	128	196	200	1250
	Long.	1.0	4.015/.0280	1.24	13800	1.40	123	188	193	1165
	Avg.		4.009/.0280	1.23	13740	1.37	123	186	190	1131

Table 44. (Cont)

Test Temp. (°F)	Dir.	Load Rate (in/min)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress α_G (ksi)	Net Stress α_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	10.0	4.014/.0281	1.24	13100	1.24	116	168	169	950
	Long.	10.0	4.005/.0280	1.25	12400	1.25	111	161	162	900
	Long.	10.0	4.005/.0280	1.25	13000	1.41	116	179	182	1096
	Long.	10.0	4.006/.0280	1.23	13000	1.32	116	173	175	1015
	Long.	10.0	4.000/.0280	1.24	12900	1.35	115	174	176	1026
	Avg.		4.005/.0280	1.24	12880	1.31	115	171	173	997
-320	Long.	10.0	4.000/.0280	1.24	13500	1.24	121	175	176	970
	Long.	10.0	4.010/.0278	1.24	13500	1.24	122	176	178	985
	Long.	10.0	4.010/.0280	1.25	13600	1.25	122	176	179	999
	Long.	10.0	3.970/.0265	1.24	13500	1.24	128	187	187	1088
	Long.	10.0	4.010/.0270	1.25	14000	1.31	130	192	194	1182
	Avg.		4.000/.0275	1.24	13620	1.26	125	181	183	1045

Table 45. Effect of Load Rate on Crack Propagation Properties of 2219-T81 Aluminum Alloy. (0.063 in. Sheet, Aluminum Company of America).

Test Temp. (°F)	Dir.	Load Rate (in/min)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	.01	4.005/.0614	1.23	8200	1.60	33.4	55.6	57.2	337
	Long.	.01	4.005/.0613	1.24	7960	1.60	32.5	54.2	55.5	317
	Long.	.01	4.000/.0617	1.23	8220	1.52	33.2	53.6	54.8	310
	Long.	.01	4.000/.0616	1.24	8360	1.61	34.0	56.8	58.4	352
	Long.	.01	4.000/.0616	1.25	8160	1.71	33.1	57.9	58.9	358
	Avg.		4.002/.0615	1.24	8180	1.61	33.2	55.6	57.0	335
-320	Long.	.01	4.005/.0614	1.26	9580	1.75	39.0	69.4	70.6	449
	Long.	.01	3.995/.0612	1.25	9280	1.70	37.9	66.[illegible]	67.6	412
	Long.	.01	3.990/.0610	1.25	9320	1.70	38.3	66.8	68.0	417
	Long.	.01	4.005/.0610	1.24	9340	1.80	38.3	69.6	70.5	438
	Long.	.01	4.005/.0610	1.24	9580	1.57	39.2	64.5	65.5	388
	Avg.		4.000/.0611	1.25	9420	1.70	38.5	67.3	68.4	421
75	Long.	1.0	4.010/.0615	1.25	8120	1.37	33.0	50.0	50.7	266
	Long.	1.0	4.000/.0614	1.24	8140	1.42	33.2	51.5	52.5	276
	Long.	1.0	4.000/.0614	1.25	8200	1.34	33.4	50.3	48.7	245
	Long.	1.0	4.005/.0608	1.26	7800	1.42	32.0	49.6	50.5	263
	Long.	1.0	3.985/.0614	1.26	7860	1.42	32.2	50.0	51.0	268
	Avg.		4.000/.0613	1.25	8024	1.39	32.8	50.3	50.6	264
-320	Long.	1.0	4.005/.0614	1.25	9700	1.48	39.4	62.3	63.2	355
	Long.	1.0	4.000/.0610	1.26	9480	1.36	38.6	58.4	59.2	310
	Long.	1.0	4.010/.0610	1.24	9440	1.45	38.6	60.3	61.2	337
	Long.	1.0	4.010/.0610	1.26	9500	1.45	38.8	60.8	61.5	341
	Long.	1.0	4.005/.0610	1.24	9700	1.45	39.6	62.0	62.7	354
	Avg.		4.008/.0611	1.25	9564	1.44	39.0	60.8	61.6	339

Table 45. (Cont)

Test Temp. (°F)	Dir.	Load Rate (in/min)	W/T	Initial Notch Length (in)	Critical Load (lbs)	Critical Crack Length (in)	Gross Stress σ_G (ksi)	Net Stress σ_N (ksi)	Fracture Toughness K_C (ksi $\sqrt{in.}$)	Strain Energy Release Rate G_C (in. lb/in^2)
75	Long.	10.0	4.010/.0616	1.24	8520	1.40	34.4	53.0	54.0	300
	Long.	10.0	4.000/.0614	1.23	8400	1.32	34.2	51.0	51.5	273
	Long.	10.0	4.000/.0616	1.24	8440	1.24	34.2	53.5	49.8	256
	Long.	10.0	4.000/.0616	1.24	8260	1.30	33.5	49.7	50.2	260
	Long.	10.0	4.000/.0615	1.24	8240	1.30	33.5	49.6	50.0	258
	Avg.		4.002/.0615	1.24	8372	1.31	34.0	51.4	51.1	269
-320	Long.	10.0	4.000/.0617	1.25	9700	1.25	39.2	57.0	57.0	293
	Long.	10.0	4.000/.0618	1.23	9700	1.23	39.3	56.8	56.5	288
	Long.	10.0	4.000/.0614	1.23	9400	1.35	38.4	57.8	58.5	308
	Long.	10.0	4.000/.0614	1.24	9460	1.40	38.4	59.2	60.5	330
	Long.	10.0	4.000/.0614	1.23	9260	1.40	37.8	58.0	59.3	316
	Avg.		4.000/.0615	1.24	9504	1.33	38.6	57.8	58.4	307

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